BIM + HEALTHCARE:

Utilization of BIM in the Design of a Primary Healthcare Project

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Submitted towards the fulfilment of the requirements for the Doctor of Architecture degree.

School of Architecture

University of Hawai‘i

DArch Project Committee

Hyoung-June Park, Chairperson

Randall Akiona

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We certify that we have read this Doctorate Project and that, in our opinion, it is satisfactory in scope and quality in partial fulfilment for the degree of Doctorate of Architecture in the School of Architecture, University of Hawai'i at Mānoa.

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"Lord, you are faithful to lead me on."

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ABSTRACT

Currently Building Information Modeling (BIM) is at the forefront of the building industry. The process of BIM involves building industry professionals and client users groups using available 3D applications and other digital media for synchronized and continuous data sharing. The BIM process includes all cooperative actions among these professionals in a design project. In contrast to a traditional design process in using 2D representative CAD applications, BIM supports 3D design and modeling with correlated information identifying object properties, calculated data and other detailed information.

While useful for various building types the definitive nature of healthcare design benefits from the BIM process largely in comparison to other building types. Healthcare design focuses on the development of a healing environment. Investigation of the environment of healthcare facilities reveals some level of evidence concerning the affect of atmosphere on the wellness of patients, caregivers and other user groups. At this time, the available credible reports supporting evidence for improving the healing environment is developing. Implementing BIM for healthcare projects is a liaison in the pursuit of Evidence-based design (EBD). The availability of solid data contributes to EBD in reaching an ideal for designing healthcare facilities. Exploring the relationship between the BIM process and the nature of Healthcare design reveals connections between the sharing of information and the gathering of information as a large contributor for the pursuit of healing environments, leading to overall advancements in healthcare design.

For this research, a case study of a design for a healthcare facility project is reviewed in its traditional process. Adopting the design project with application of a BIM process of design, rather than the traditional process, establishes a level of comparison highlighting the results of BIM in healthcare design. With regards to critical aspects in the nature of healthcare BIM strategies are utilized for the investigation of the case study project. In this document BIM is employed with a couple of detailed studies for phasing the design process of the healthcare project, creating modeling prototypes, and making reference to a baseline model in order to increase the overall success of the healthcare design project.

1. INTRODUCTION

In this section the project statement is introduced. Additionally, the history and development regarding Building Information Modeling and healthcare design are addressed providing the ideas which led up to the investigation of this project.

1.1. PROJECT STATEMENT

Building Information Modeling (BIM) is cooperative actions between building industry professionals and client user groups, all using available 3D applications and other digital media for simultaneous and consistent data sharing in an on-going design project.[1 2 3] BIM provides the capabilities of interfacing and correlating multiple layers of various kinds of information. The categories of information are 1) visual representation, which is the information consisting of object properties and object-oriented graphic components database entries, 2) calculated information which includes specifications, costs and drawings schedules and 3) documentation of relationships and responsibilities consisting of contracts, warranties, maintenance information, etc.[4] Ideally, BIM would be fully integrated among all professions with various collaborative projects having a functional information processing linked to one another. While BIM has been applied to various building types, the methods used are not fully developed for healthcare projects. In the case of healthcare design projects, utilizing BIM is an efficient process which supports the coordination of multiple variables found in healthcare facilities. Furthermore, the collected data from credible research, evaluations and evidence gathered from the operations of the patients, doctors, clients and other partakers of the health facility become critical

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[1] Chuck Eastman et al., *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors* (Hoboken, NJ: Wiley, John & Sons, Inc., 2008).
[2] H.J. Park, “BIM + Evolution: The Utilization of Building Information Modeling at an Early Design Stage” (paper presented at the University of Hawaii at Manoa, School of Architecture, Honolulu, Hawaii, 2007).
[3] Filiz Ozel, “Building Information Modeling for Healthcare Facilities” (Microsoft PowerPoint, Arizona State University - College of Design, May 19, 2008).
[4] Matthew Kennedy, “Great Expectations: BIM for Healthcare,” *The Samborn Report (Dimensions Newsletter)*, no. Summer 2008, http://www.ssoe.com/news/article2.aspx.

factors to make design decisions. This type of design method has been developed as "Evidence-Based Design (EBD)."[5] Since Roger Ulrich pioneered the study of EBD in 1984 with his paper, "View through a window may influence recovery from surgery," EBD has become prevalent in healthcare design.[6] Weill Greenberg Center in New York[7] is recognized for the exemplary use of EBD. In this paper, issues regarding healthcare facilities are presented and various strategies of using BIM are explored based on the specific nature of healthcare through a case study of a primary healthcare facility renovation.

1.2. A BRIEF HISTORY ON PROCESS-ORIENTED BIM

Currently, BIM has become increasingly prevalent in the building industry. However new BIM may seem, according to Eastman, the concepts, approaches and methods we now recognizes as BIM have been identified approximately 30 years ago with the earliest documented example identified as "Building Description System" – a working prototype published by the AIA Journal, by Charles Eastman, then later at Carnegie-Mellon University, in 1975. Since then, the research and development of this concept produced different terminologies carrying the same definition and were used through the years in different countries. Consolidating the terminology to a more recent English term of "Building Modeling" – in the sense that "Building Information Modeling is used today – initially appeared, in 1986, in the title of a paper written by Robert Aish. His paper includes 3D modeling, automatic drawing extraction, intelligent parametric components, relational databases, temporal phasing of construction processes and so forth. Shortly after the current use of the English

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[5] Robert Anthony, "Definition of Evidence-Based Design for Healthcare," *The Center for Health Design*, 2009, http://www.healthdesign.org/aboutus/mission/EBD_definition.php.
[6] Roger Ulrich, "View through a window may influence recovery from surgery," *Science*, April 27, 1984.
[7] Chris Gaerig, ed., "Weill Greenberg Center New York, New York Polshek Partnership Architects/Ballinger," *Healthcare Design*, 2008.

term, “Building Information Model” appeared December of 1992 in a paper, *Automation in Construction* by authors G.A. van Nederveen and F. Tolman.[8]

Prior to the BIM, the history or architectural documentation was exercised through drawings representing a building. Regardless of whether the drawings are physically or digitally produced, they make up an annotated booklet of instructions for constructing a building. These drawings containing plans, sections and elevations are composed of skillfully drafted lines, where each line is a part of a larger abstraction meant to communicate design intent. In times of antiquity, the master builder had responsibilities of managing these documents as both architect and builder. Later buildings increased in complexity and the response was specializations in the design and construction process emerged. Leading from this an exponential increase in the complexity of buildings from the industrial revolution until our current day has brought documentation sets spanning all disciplines and professions resulting in hundreds of drawings shared among several people.

While today we no longer rely on pen and paper to produce drawings and computer technology (computer-aided design, also known as CAD) has become the replacement, drawings are still largely generated with a traditional design process among separate disciplines, in 2D, non-intelligent, lines and text.[9] Contrasting the traditional process of design, illustrated in Figure 1, BIM offers a new process of communicating the information, roles and responsibilities necessary for the design and construction of a building.

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[8] Chuck Eastman et al., *BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors* (Hoboken, NJ: Wiley, John & Sons, Inc., 2008).
[9] Ibid.

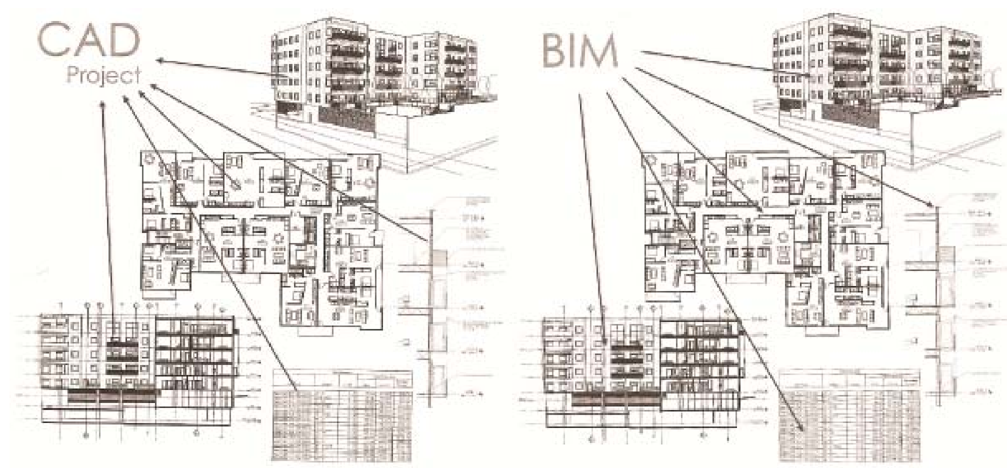

Figure 1 ***Typical CAD outputs & typical BIM outputs.***[10]

BIM is process-oriented, rather than separate disciplines creating drawings with little or no intelligent connections between each other, assembling all information in to one location and cross linking the data among associated objects.[11]

1.3. ORIGINS OF HEALTHCARE DESIGN

Before any standard had become established for healthcare or its facilities, healing was sought out through culture or religion. Healing had yet to be connected to scientific research. Due to religious/cultural viewpoints, health was observed and understood based on those perspectives. In the 19th century advances in chemistry and laboratory techniques and equipment led into what we now call modern medicine. It is with this development of medicine and technology, religious views for healing having become confronted with the scientific evidences of medicine.[12] As for the affects of healing based on environment, in 1860, Florence Nightingale was very observant and her notes are the earliest documentation recognized for researching the affects of the environment on a people's health conditions. Her *Notes on Nursing* reveals her observations that "suffering associated with disease is most often not from

[10] Greg Demchak, Tatjana Dzambazova, and Eddy Krygiel, *Introducing Revit Architecture 2009: BIM for Beginners*, 2nd ed. (Indianapolis, Indiana: Wiley Publishing, Inc., 2008).
[11] Greg Demchak, Tatjana Dzambazova, and Eddy Krygiel, *Introducing Revit Architecture 2009: BIM for Beginners*, 2nd ed. (Indianapolis, Indiana: Wiley Publishing, Inc., 2008).
[12] Sir William Osler, "The Evolution of Modern Medicine," *Electronic Text Center*, 1997.

the disease itself but from the lack of basic human comforts such as fresh air, light, warmth, quiet, cleanliness and nutrition."[13] It wasn't until much later formal research based on this concept began. Apart from a healing environment, research in medicine continued to fruition. By the time the 20th century rolled around scientific research has been leading the development of healing and healthcare. In 1972, this practice of advancing medicine through a systematic scientific method of research became increasing acceptable because of a Scottish epidemiologist named Professor Archie Cochrane who wrote a book called Effectiveness and *Efficiency: Random Reflections on Health Services*.[14] Then the term, "Evidence-based medicine" (EBM) first appeared in a paper written by Gordon Guyatt *et al.* called *Evidence-Based Medicine: A New Approach to Teaching the Practice of Medicine*. According to Sackett *et al*., Evidence-based medicine (EBM) is formally defined as "the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients." The practice of evidence based medicine means integrating individual clinical expertise with the best available external clinical evidence from systematic research."[15] Since the development of medicine concepts originally recognized by Nightingale back in 1860 were instinctively resurfaced as concerns during the early years of hospital buildings.

Healthcare design is the result of cumulative perspectives on providing basic human needs, methods of caring and curing infirmities, and pursuing healing environments. Neil Kellman wrote his paper, *History of Healthcare Environments* based on these issues and he addresses the effect of modern architecture on the practices for seeking health and healing. He writes, "Many aesthetics born of the modern architecture movement can be seen in today's hospitals: the clean, sterile lines, lack of ornamentation, and so forth. Over a period of 50 or 60 years, many of these aesthetic standards have come to be accepted as the way hospitals ought to be....Unconsciously, people began to realize that the places they were going for their

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[13] Linda McAllister, "Who Was Florence Nightingale and Why Is She Important Today?," *Children's Health System*, 2007, http://magnet.chsys.org/default.aspx?id=102.

[14] Archibald Cochrane, *Effectiveness and efficiency: random reflections on health services* (London: Royal Society of Medicine, Press, 2004), http://www.worldcat.org/oclc/248148013.

[15] David Sackett et al., "Evidence based medicine: what it is and what it isn't," *BMJ Journals* 1996, no. 312, Editorials (January 13,): 71-72.

healthcare were not meeting a host of *needs* beyond the actual procedures rendered." The value people are searching for in healthcare is to be treated as a human in every aspect; acknowledging the worth of the individual patient. Since then, these *needs* have become recognized through the advancements in medical knowledge, developments in healthcare technology and awareness concerning the importance of the healing environment. Stemming from Evidence-based medicine brought the process of basing decisions relative to the built environment on credible research to achieve the best possible outcomes known as "Evidence-based design" thereby linking the search for healing to our environment. Nightingale's concepts were formalized during this time. Later with Roger Ulrich's ground-breaking efforts to pursue further investigation on these concepts, beginning in 1984, evidence-based design has become ubiquitous among the healthcare design industry.[16]

Since this realization, healthcare design has engaged various domains of information recognized as strongholds for facilitating a building that promotes wellness. The advancements of these domains have brought the healthcare industry and designing for healthcare to levels of great complexity. The amount of information necessary to evaluate for the design of a healthcare building has expanded exponentially since the early hospital facilities that emerged around the 1920s.[17]

Following traditional methods of architectural design, Richard Foque, an architect specializing in health buildings, believes that 'the starting point...is an interdisciplinary approach based on a holistic perception of man and environment.' During a lecture given at the Royal Institute of British Architects in May 1999 Foque reiterated the traditional and linear process of design over the span of time, shown in Figure 2. From this he explains the development of design from abstract to concrete and then illustrates this process in relationship to the domains of information involved in designing for healthcare.[18]

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[16] Roger Ulrich, "View through a window may influence recovery from surgery," *Science*, April 27, 1984.
[17] Neil Kellman, "History of Health Care Environments," *Journal of Healthcare Design: Proceedings from the First Symposium on Healthcare Design* 1 (1988): 19-27.
[18] Ibid.

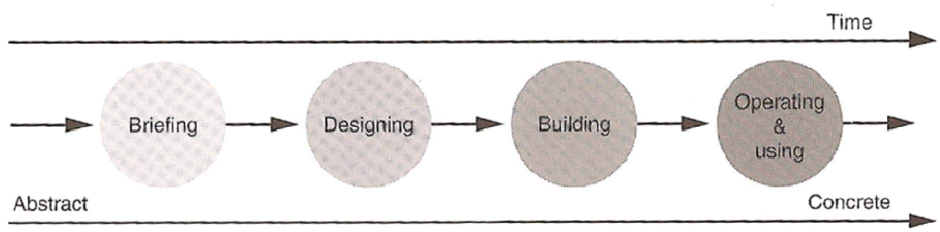

Figure 2 ***Richard Foque illustrates the traditional, linear process of design which is irreversible in time.***[19]

His diagrams reflect when separate areas of information fall into the traditional process of design (Figure 3). The domains of information demonstrate the growth of research and development in important aspects of healthcare and how these are managed throughout the duration of a design project.

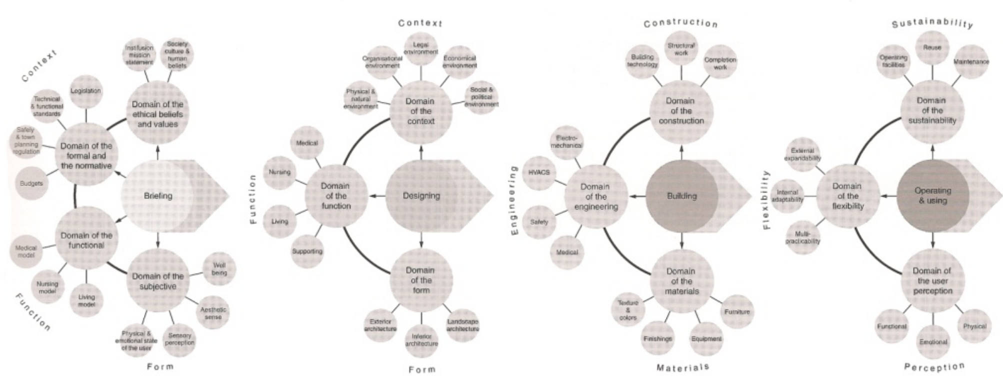

Figure 3 ***Richard Foque – four important domains for the design of a primary healthcare facility.***[20]

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[19] Geoffrey Purves, *Healthy living centres: a guide to primary health care design* (Oxford: Architectural Press, 2002).
[20] Geoffrey Purves, *Healthy living centres: a guide to primary health care design* (Oxford: Architectural Press, 2002).

Currently, healthcare design is the measure of planning for basic human needs, methods of caring and curing infirmities, and pursuing healing environments using a traditional process of design used among the building industry. Since the movement of Evidence-based design, beginning with Roger Ulrich, research and development of credible information regarding the healthcare environment has increased largely in the last 25 years. Managing the expanse of information required to design for a healthcare facility continues to reach new levels of complexity with the advancements in medical knowledge and technology. In healthcare, good design acknowledges the worth of the individual, looks to scientific evidence to find technical excellence in machinery and to a biological basis for caring design. Designing for healthcare also reflects on past results to find confidence that beauty still exist in the field of healthcare design.[21]

1.4. SUMMARY

The full integration of BIM among all professions is the ideal. So that a range of collaborative projects would have fully functional information processing linked to one another. While the concept of BIM and its advantages are recognized and the BIM ideal is projected in every extent of the building industry, the pursuit for BIM implementation has been attempted on several projects of various building types successfully. Some of these building types are including commercial, residential, civic, educational, performance and sports complex buildings such as, the Hillwood Commercial Project in Dallas, Erie on the Park residential tower in Chicago, the San Francisco Federal Building, Cooper Union for the Advancement of Science and Art New Academic building, the Opera Theatre, Sydney Opera House, and the Beijing National Swimming Centre. Initially BIM has been used for other building types aside from healthcare facilities. Since the development of BIM, the previous methods of application have been attempted in healthcare design. However this does not fulfill full implementation of BIM into healthcare design.

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[21] Neil Kellman, "History of Health Care Environments," *Journal of Healthcare Design: Proceedings from the First Symposium on Healthcare Design* 1 (1988): 19-27.

In regards to healthcare design, Evidence-based design (EBD) stems from Evidence-based medicine (EBM). A concern from this according to Stankos and Schwarz is,

> "Can the theoretical base and methods that are used in medical research be 'borrowed' by the design field?....EBM is anchored in theoretical knowledge rooted in medical research that is undertaken with the explicit purpose of answering a question or solving a problem, but at the same time aims to test, evaluate and improve the research process employed."[22]

Stankos and Swartz claim EBD is locked into a knowledge base which hardly contains theoretical explanation and so cannot be used to understand the outcomes of design solutions.

"Thus, EBD should be used carefully in healthcare design, and caution should be used in the generalization of evidence from a limited number of credible research studies. This is why a basic systematic review of the existing and future studies is essential. This kind of meta-analysis will enable designers to choose the appropriate type of evidence from research to improve the accuracy of predictions in environmental design."[23]

This D. Arch project investigates BIM in healthcare design. Healthcare design requires an alternative method in order to achieve full BIM implementation. The productivity and efficient information sharing of the BIM enhance the maximum use of EBD in a primary healthcare project. A realistic representation of space consistently manifested based on the current information is the ideal for making the most calculative design decisions. The full implementation of BIM in healthcare design will reap further growth in the healthcare knowledge base and thereby endorse evidence-based design.

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[22] Mary Stankos and Benyamin Schwarz, "Evidence-Based Design in Healthcare: A Theoretical Dilemma," *Interdisciplinary Design and Research e-Journal* 1, no. 1, Design and Health (January 2007): 1-15.
[23] Ibid.

2. PROBLEM STATEMENT

2.1. NEED FOR BIM IN HEALTHCARE

Healthcare design has a direct and intentional purpose to ally with healthcare professionals for promoting wellness. The consistency of the goals and repetitive activities that occur within the building, leads to regular processing of information.[24] BIM will support and permit advances in healthcare as a library of information relative to the building. In light of this, BIM also influences the quality of EBD. Healthcare design benefits from BIM because even with multiple layers of design data BIM guides a healthcare design direction toward promoting wellness effectively. The critical nature of healthcare, diagramed in Figure 4, corresponds to the methods of diagnosing/treating patients, providing functional space and housing tools and equipment.

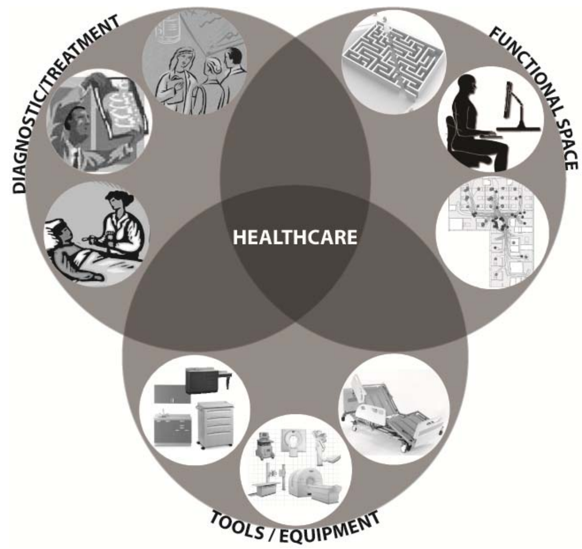

Figure 4 ***Diagram depicting aspects in the nature of healthcare.***

1) Treating patients includes discussions, examinations, operations, and/or checking results. According to Princeton's WordNet – a lexical database of English,

[24] Filiz Ozel, "Building Information Modeling for Healthcare Facilities" (Microsoft PowerPoint, Arizona State University - College of Design, May 19, 2008).

"treatment" is the "care provided to improve a situation." Treating patients revolve around the initial actions when a patient first arrives to a healthcare facility and any actions that may follow as a result of the patient's condition.[25] Miscommunication and delay in productivity occur from the consultation between healthcare professional and patient, or administrative reasons such as form-filling, note-taking, and the clerical errors like missing appointments or medical records.[26] 2) Providing the functional space for healthcare professionals is another essential part in healthcare. The spaces for these departments are shaped differently based on activity, equipment and other specific needs. It is vital to have well designed, functional environment. For example poorly designed, overcrowded patient care areas were found to be a large contributing factor to nurses feeling frustration, leading to increased human error in patient treatment, negative attitudes; overall resulting in unsafe healthcare practice. This is completely against the main purpose of the healthcare profession so it is vital to have well designed, functional environment.[27] 3) Housing the sophisticated tools and equipment also has a significant role in the nature of healthcare. Designing for healthcare equipment is vital because healthcare is so dependent on these sophisticated tools for diagnosis and readings' results. The difficulty comes with space designed rigidly to one piece of equipment when technology advances and redesigning for updated equipment or new equipment is required. Designing with anticipation of future developments in healthcare technology remains to be an issue.[28] Among all the facets involved in the healthcare profession, designing for it can be challenging. Additionally, attempting to pursue EBD for various different issues involved in the healthcare environment is challenging with the plethora of detailed

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[25] H.R.H. Patel et al., "Outpatient clinic: where is the delay?," *Journal of the Royal Society of Medicine* 95, no. December 2002 (2002): 604-605.

[26] Ibid.

[27] Matthew Carmona, Sarah Carmona, and Wendy Clarke, *A Bibliography of Design Value for The Commission for Architecture and the Built Environment* (London: University College London - The Bartlett School of Planning, 3, 2003), http://www.cabe.org.uk/files/a-bibliography-of-design-value.pdf.

[28] Orlando Maione, ed., "Open Building: A New Paradigm in Hospital Architecture," *AIA Academy Journal* (October 27, 2004), http://info.aia.org/journal_aah.cfm?pagename=aah_jrnl_openbuilding_102704&dspl=1&article=article.

information and variables affecting the entire environment. These issues make healthcare design more challenging.

2.2. SUMMARY

The nature on which healthcare design is based upon, BIM is a compatible process of design. The process of BIM provides accessibility to solid data information which is applicable to EBD explorations. Thus, BIM advances the effectiveness of healthcare design as a whole.

3. SCOPE OF RESEARCH

3.1. BIM + HEALTHCARE

BIM has the capacity to amalgamate a bridge between the healing environment and the services of the healthcare professionals. As a tool for evidence-based design, BIM is employed as a liaison between patient outcome data and specific building conditions and locations. Figure 5 illustrates the concept of various types of information managed through the BIM process and serving as reliable data contributing to further development of EBD.

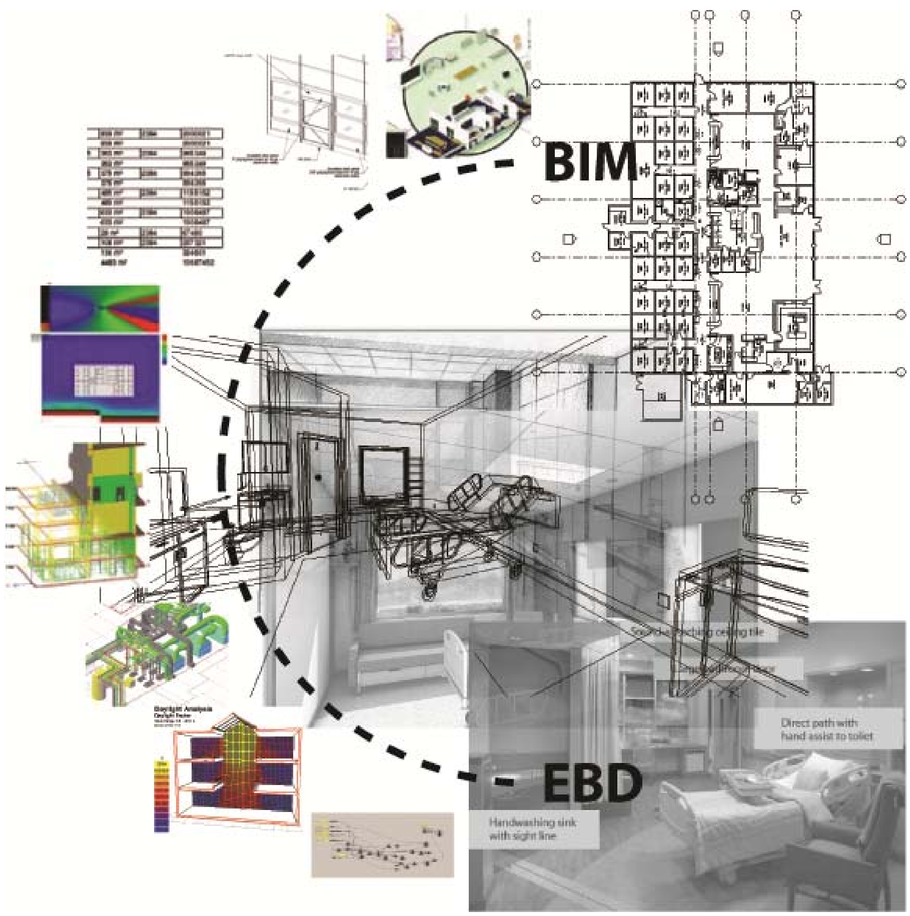

Figure 5 ***BIM contributes solid data to further Evidence-based design.***

3.2. ENVIRONMENT OF PATIENTS AND CAREGIVERS

A few Healthcare challenges centre on maintaining environmental control for patient safety in areas such as air quality, energy control, noise factor, communication and infection control. Solutions are developed by adapting healing patterns which are achieved by monitoring quality of design which can be done so by establishing parameters under BIM tools.[29] Also, administered by a hospital's facilities management department, a BIM model can be the reference library for all product and equipment information enabling the creation of maintenance schedules, standards manuals, and purchase orders.[30]

In order to use BIM has a connection between patient outcome data and the environment; the outcomes established thus far through EBD provide a starting point for understanding the environment of patients and caregivers. These suggested solutions developed from EBD serve as a foundation for developing the parameters under BIM tools. Referencing the *Literature Review on Evidence-Based Healthcare Design,* three general outcomes of EBD relate to 1) patient safety issues such as infections, medical errors and falls, 2) other patient outcomes relating to pain, sleep, depression, length of stay, spatial orientation, privacy, communication, social support and overall patient satisfaction and 3) staff outcomes such as injuries, stress, work effectiveness and satisfaction. Due to repetition in the outcomes of research, a part 4) summarizes these finding of EBD. Understanding these generalized outcomes of EBD is important for establishing a foundation for applying the BIM process.[31]

3.2.1. Patient Safety Issues

Patient Safety is the first section of the review which shows general outcomes in areas such as infections, medical errors and falls. According to documentation for

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[29] Filiz Ozel, "Building Information Modeling for Healthcare Facilities" (Microsoft PowerPoint, Arizona State University - College of Design, May 19, 2008).
[30] Matthew Kennedy, "Great Expectations: BIM for Healthcare," *The Samborn Report (Dimensions Newsletter)*, no. Summer 2008, http://www.ssoe.com/news/article2.aspx.
[31] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 3.

EBD, the design of the physical environment can impact nosocomial (hospital-acquired) infection rates by affecting three major transmission routes – air, contact and water.[32] With a large amount of documentation for EBD the review strongly supports the following measures for controlling and preventing infections:

• Use effective air quality control measures during construction and renovation to prevent the outbreak of airborne infections. Measures include, for example, using portable high-efficiency particulate air (HEPA) filters, installing barriers between patient-care areas and construction/renovation areas, generating negative air pressure for construction/renovation areas relative to patient-care areas, and sealing patient windows.

• Install alcohol-based hand-rub dispensers at the bedside and in other accessible locations to increase hand-washing compliance and reduce contact transmission of infection.

• Select easy-to-clean floor, wall, and furniture coverings, and employ proper cleaning and disinfection procedures.

• Design and maintain the water system at the proper temperature and adequate pressure; minimize stagnation and back flow; eliminate dead-end pipes; regularly clean point-of-use fixtures; and consider the location of decorative fountains and carefully maintain them to minimize the risk of waterborne infection.

• Provide single-bed rooms with private toilets to enable separation or isolation of patients on admission, so that those with unrecognized infections can be tested and identified without being mixed in with uninflected individuals in multibed rooms; to reduce airborne infection transmission by increasing isolation capacity and facilitating the maintenance of good air quality through measures such as effective ventilation, filtration, and appropriate air flow direction and pressure (positive or negative); and to facilitate thorough cleaning after a patient leaves, including the use of

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[32] Ibid., 4.

decontamination methods such as hydrogen peroxide vapor (HPV), which may be much more effective than conventional cleaning.[33]

Designing for patient safety also takes into account the outcomes based on medical errors. Based on limited EBD literature medical errors are caused by both the mistakes of individuals and also a combination of people and the environment. Factors relating to medical errors include noise, light, and acuity-adaptable, single-patient rooms. The limited literature available reveals evidence of error rates increasing sharply when there is an interruption or distraction from an unpredicted noise.[34] Poor lighting levels can affect the performance of healthcare workers and lead to these medical errors.[35] Additionally, verified by pragmatic studies the use of acuity-adaptable rooms reduces possible sources of medical error such as in transfers, delays, communication discontinuities among staff, loss of information, and changes in computers or systems which in turn lowers the error rates.[36]

Thirdly, designing to prevent falls is part of designing for the overall safety of patients. There is a significant amount of documentation that examines the causes and risks factors involved with patient falls in hospitals. Designing for patient safety against falls is important because those who fall incur physical injuries and adverse psychological effects and have greater lengths of stay in a hospital.[37] Interestingly, the role of the environment in causing or preventing patient falls is accepted among many. There is no certain evidence linking environmental interventions with reduced falls. Studies were made in attempt to identify the design issues that may have contributed to falls such as the placement of doorways, handrails, toilets, etc. but none have made comparisons between different design options to determine the

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[33] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 5.

[34] E. A. Flynn et al., "Impact of interruptions and distractions on dispensing errors in an ambulatory care pharmacy," *American Journal of Health Systems Pharmacy* 56, no. 13 (1999): 1319-1325; U. A. Kistner et al., "Accuracy of dispensing in a high-volume, hospital-based outpatient pharmacy," *American Journal of Hospital Pharmacy* 51, no. 22 (1994): 2793-2797.

[35] T. L. Buchanan et al., "Illumination and errors in dispensing," *American Journal of Hospital Pharmacy* 48, no. 10 (1991): 2137-2145.

[36] A. Hendrich, J. Fay, and A. Sorrells, "Courage to heal: Comprehensive cardiac critical care," *Healthcare Design*, 2002.

[37] S. Brandis, "A collaborative occupational therapy and nursing approach to falls prevention in hospital inpatients," *Journal of Quality in Clinical Practice* 19, no. 4 (1999): 215-221.

independent impact of a single design factor on the frequency of falls. At this point, more research and more rigorous studies are needed to confirm any findings and which can identify variables involved with the cause or prevention of patient falls.[38]

3.2.2. Other patient outcomes

General results of EBD are other patient outcomes which include pain, sleep, depression, length of stay, spatial orientation, privacy, communication, social support and overall patient satisfaction.

Unfortunately pain is a persistent and severe problem in hospitals. Although the growing scientific evidence has revealed that exposing patients to nature in true and various other forms can produce substantial and clinically important alleviation of pain, which is very encouraging.[39] Some research also suggests that patients experience less pain when exposed to higher levels of daylight in contrast to lower levels of daylight in their hospital rooms. So designing with large windows affording views of nature for patient rooms, or procedure spaces, treatment rooms, waiting areas will aid in the reduction of pain patients may be suffering through.[40] Various forms of conveying nature, whether it is in artwork, visual and auditory simulations of nature divert or capture the attention of a patient and thereby are effective in relieving some pain. Theories and research imply patients should not be placed in spaces which lack nature distractions and which contain other stressors such as noise because this can

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[38] Roger Ulrich et al., “A Review of the Research Literature on Evidence-Based Healthcare Design,” *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 21.

[39] S. Malenbaum et al., “Pain in its environmental context: Implications for designing environments to enhance pain control,” *Pain* 134 (2008): 241-244; R. S. Ulrich et al., “The environment’s impact on stress,” in *Improving healthcare with better building design*, ed. S. Marberry (Chicago: Health Administration Press, 2006), 37-61; R. Ulrich, “Biophilic theory and research for health design,” in *Biophilic design: Theory, science and practice*, ed. S. Kellert, J. Heerwagen, and M. Mador (New York: John Wiley, 2008).

[40] R. Ulrich, “Biophilic theory and research for health design,” in *Biophilic design: Theory, science and practice*, ed. S. Kellert, J. Heerwagen, and M. Mador (New York: John Wiley, 2008).

exacerbate pain.[41] Planning for nature views should be pursues in all aspects including site planning and orientation of a building.[42]

Designing for improving patient sleep is very important since there is an increased need for sleep due to the patient illness. Often while a patient is hospitalized they suffer from poor sleep which significantly hinders their ability to heal.[43] Evidence confirms that this common problem in hospitals can be improved upon by designing for single-bed rooms which reduces noise disturbance from roommates, visitors and healthcare staff.[44] Also, installing high-performance sound-absorbing materials to reduce extreme sound conditions will improve sleep.[45] Additionally, patient rooms should be oriented and designed to receive natural daylight. This helps the patient retain normal circadian rhythms.[46] All of these design considerations help patient sleep and in turn help improve their ability to heal.

Several design suggestions for improving other patient outcomes are helping to also reduce the stress level outcome of patients, such as real or simulated nature views, gardens, art (more so of art depicting nature rather than abstract art which research shows can cause stressful reactions). Designing for the reduction of noise level according to similar methods mentioned for improving patient sleep are applied

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[41] S. Malenbaum et al., "Pain in its environmental context: Implications for designing environments to enhance pain control," *Pain* 134 (2008): 241-244.

[42] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 23.

[43] Ibid., 24

[44] M. T. Southwell and G. Wistow, "Sleep in hospitals at night—Are patients' needs being met?," *Journal of Advanced Nursing* 46, no. 2 (1995): 1101-1109; A. M. Yinnon et al., "Quality of sleep in the medical department," *British Journal of Clinical Practice* 46, no. 2 (1992): 88-91.

[45] S. Berg, "Impact of reduced reverberation time on sound induced arousals during sleep," *Sleep* 24, no. 3 (2001): 289-292; I. Hagerman et al., "Influence of intensive coronary care acoustics on the quality of care and physiological state of patients," *International Journal of Cardiology* 98, no. 2 (2005): 267-270; M. K. Philbin and L. Gray, "Changing levels of quiet in an intensive care nursery," *Journal of Perinatology* 22, no. 6 (2002): 455-460.

[46] A. BaHammam, "Sleep in acute care units," *Sleep and Breathing* 10, no. 1 (2006): 6-15; T. Wakamura and H. Tokura, "Influence of bright light during daytime on sleep parameters in hospitalized elderly patients," *Journal of Physiological Anthropology and Applied Human Science* 20, no. 6 (2001): 345-351.

here as well. Creating much quieter environments during construction or renovation to a building is a high priority.[47]

Again, similarly to other general patient outcomes, depression can be reduced by designing for the allowance of daylight. Evidence shows that bright artificial light or daylight is effective in reducing depression and improving mood. According to Ulrich, "The evidence that patients' depression is diminished by daylight exposure implies the importance of the orientation and site planning of healthcare buildings."[48] Design should ensure patients have more than enough daylight by means of larger windows or in the case sufficient daylight is not available consider bright artificial light.[49]

As for outcomes relating to the length of stay of patients there is very limited research regarding this issue. There are a few strong studies which regularly identify positive impact on patients by designing for both light and nature views. However, further research and testing on a broader range of patient types is necessary to confirm the current findings.[50]

According to Ulrich et al, "Wayfinding problems in hospitals are costly and stressful and have a particular impact on outpatients and visitors, who are often unfamiliar with the hospital and are otherwise stressed and disoriented." There is a large amount of research on wayfinding through hospitals and other complex buildings but there is minimal research on the performance of different wayfinding systems or how a wayfinding system may impact other healthcare outcomes.[51] Hospitals should integrate wayfinding systems that include coordinated elements such as visible and easy-to-understand signs and numbers; clear and consistent verbal

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[47] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 28.

[48] R. S. Ulrich et al., "The environment's impact on stress," in *Improving healthcare with better building design*, ed. S. Marberry (Chicago: Health Administration Press, 2006), 37-61.

[49] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 33.

[50] Ibid., 34.

[51] Ibid., 35-36.

directions along with clear and consistent paper, mail-out, and electronic information; and a legible physical setting.[52]

Very little documentation for EBD exists for the issue of improving patient privacy and confidentiality. This is an important issue recognized and protected by the U.S. law through the Health Insurance Portability and Accountability Act (HIPAA). Not enough privacy can lower patient satisfaction. Also patient outcomes can worsen if patients withhold personal information or refuse to be examined due to privacy concerns.[53] Some design approaches which address this issue is by provision of single-bed rooms which increases privacy and confidentiality,[54] installing hard-wall partitions to provide speech privacy[55] and also extending these hard-wall partitions to the support ceiling or deck. Another approach is putting in high-performance sound-absorbing ceiling tiles[56] and even designing to include private discussion rooms close to waiting, admission and reception areas.[57] These design approaches help to support speech privacy; how well a private conversation can be overheard by and unintended listener.

Improving communication with patients and family members can provide social support and can help facilitate family members' involvement in patient care and increase patient satisfaction with care.[58] Again studies reveal that providing single-

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[52] Ibid., 36.

[53] D. Barlas et al., "Comparison of the auditory and visual privacy of emergency department treatment areas with curtains versus those with solid walls," *Annals of Emergency Medicine* 38, no. 2 (2001): 135-139.

[54] Press Ganey, Inc. "National satisfaction data for 2003 comparing patients with versus without a roommate," Provided by Press Ganey, Inc.

[55] D. Barlas et al., "Comparison of the auditory and visual privacy of emergency department treatment areas with curtains versus those with solid walls," *Annals of Emergency Medicine* 38, no. 2 (2001): 135-139; J. Karro, A. W. Dent, and S. Farish, "Patient perceptions of privacy infringements in an emergency department," *Emergency Medicine Australasia: EMA* 17, no. 2 (2005): 117-123; E. J. Mlinek and J. Pierce, "Confidentiality and privacy breaches in a university hospital emergency department," *Academic Emergency Medicine* 4, no. 12 (1997): 1142-1146.

[56] I. Hagerman et al., "Influence of intensive coronary care acoustics on the quality of care and physiological state of patients," *International Journal of Cardiology* 98, no. 2 (2005): 267-270; M. K. Philbin and L. Gray, "Changing levels of quiet in an intensive care nursery," *Journal of Perinatology* 22, no. 6 (2002): 455-460.

[57] A. Joseph and R. Ulrich, "Sound control for improved outcomes in healthcare settings," *The Center for Health Design* January, no. 4 (2007).

[58]Laitinen and Isola, "Promoting participation of informal caregivers in the hospital care of the elderly patient: Informal caregivers' perceptions," *Journal of Advanced Nursing* 23, no. 5

patient rooms and private discussion areas support communication[59] and only some studies show the use of dim lighting rather than bright lighting in counseling rooms achieve better result in counseling sessions.[60] Aside from this further research is needed to explore the environment-communication relationship in various healthcare settings along with how design measures can enhance communication.[61]

Overall patient satisfaction is predictable with environmental satisfaction in healthcare settings.[62] Based on evidence the needs of the patients and family members should be a priority when designing for healthcare spaces, providing a comfortable and aesthetically pleasing environment. This can be achieved by use of color, artwork, and so forth. Design should also include window views of nature, appropriate lighting or sunlight and information guides. Single patient rooms for a number of patient outcomes can provide features such as quietness, privacy, accessibility to a bathroom which creates a sense of control and thereby contributing to the overall satisfaction of the patients' healthcare experience.[63]

3.2.3. Staff Outcomes

A third section that addresses general outcomes of EBD is staff outcomes. Staff outcomes included items such as injuries, stress, work effectiveness and satisfaction.

Occupational injury is not uncommon to staff workers in a healthcare facility. Studies have been done evaluating the physical stress and strain due to patient

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(1996): 942-947; Press Ganey, Inc., "Hospital pulse report: Patient perspectives on American health care," 2007, http://www.pressganey.com/galleries/default-file/Hospital_Pulse_Report_2009.pdf.

[59] P. Astedt-Kurki et al., "Interaction between adult patients' family members and nursing staff on a hospital ward," *Scandinavian Journal of Caring Sciences* 15, no. 2 (2001): 142-150; D. O. Kaldenburg, "the influence of having a roommate on patient satisfaction" (Press Ganey Satisfaction Monitor, 1999).

[60] Y. Miwa and K. Hanyu, "The effects of interior design on communication and impressions of a counselor in a counseling room," *Environment and Behavior* 38, no. 4 (2006): 484-502.

[61] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 36.

[62] P. B. Harris et al., "A place to heal: Environmental sources of satisfaction among hospital patients," *Journal of Applied Social Psychology* 32, no. 6 (2002): 1276-1299.

[63] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 43.

handling. One design consideration that has been recognized for reducing the frequency of injury and cost of injury claims of hospital workers in including ceiling lifts into the design. While the studies have shown reduction in injuries or cost of injuries it is critical to have a comprehensive lifting program along with the ceiling lifts. It is still a challenge to isolate the effects of the lifts alone in recent studies because of a combination of lifts involved in the studies and cultural change in the hospital settings.[64]

Healthcare providers experience a high level of work stress, just like patients experiencing less stress by the reduction of noise, or use of bright lighting or being placed in single-bed patient rooms. Staff workers also experience less stress. Using high-performance, sound-absorbing materials to reduce noise levels, administering bright lights for night staff[65] and designing for single-bed patient rooms[66] have all been identified in studies to reduce the stress of hospital workers as well.

As for designing to increase staff effectiveness, relevant studies are still limited. According to Ulrich et al., "Jobs by nurses, physicians, and other healthcare workers often require a complex choreography of direct patient care, critical communications, charting, accessing technology and information and other tasks."[67] Some physical environmental involvements that have shown some affect on staff effectiveness relates to unit configuration, noise, lighting and other types of distractions. Further research is still necessary to further understand how the environment affects staff effectiveness.[68]

Overall staff satisfaction is mostly is influenced by nonphysical conditions relating to autonomy,[69] compensation[70] and performance.[71] However the physical

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[64] Ibid., 45.
[65] Ibid., 47.
[66] D. D. Harris et al., "The impact of single family room design on patients and caregivers: Executive summary," *Journal of Perinatology* 26 (2006): s38-s48.
[67] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 49.
[68] Ibid.
[69] K. O'Rourke et al., "Job satisfaction among nursing staff in a military health care facility," *Military Medicine* 165, no. 10 (2000): 757-761.
[70] M. F. Best and N. E. Thurston, "Canadian public health nurses' job satisfaction," *Public Health Nursing* 23, no. 3 (2006): 250-255.

environment can either support or worsen working conditions which affects the stress level of the workers. Not many studies have examined the effects of environmental factors in relationship to job-satisfaction. Natural light is the only area where some studies have touched on this topic.[72]

3.2.4. Overview of general outcomes of EBD

Overall, there is a strong presence of design approaches involving single-bed rooms, accessibility to daylight, views of nature, areas zoned for family and visitors, the possible use of carpeting, using noise-reducing materials, installing ceiling lifts, configuring layouts specific to hospital staff, etc. Presently, there is some accumulation of scientific studies which support these positive outcomes due to EBD. However, to strengthen the role of EBD in positively impacting the healthcare environment there needs to be further studies on different isolated factors involved in a healthcare setting. The growth of EBD is dependent on solid information gathered and evaluated to support design ideas for improving the healthcare environment. Observing the established outcomes (Figure 6) from EBD provides a foundation and starting point for using BIM to support investigations to further the credible studies of EBD.

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[71] M. K. Douglas et al., "The work of auxiliary nurses in Mexico: Stressors, satisfiers and coping strategies," *International Journal of Nursing Studies* 33, no. 5 (1996): 495-505.
[72] Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," 52.

TABLE 1:
SUMMARY OF THE RELATIONSHIPS BETWEEN DESIGN FACTORS AND HEALTHCARE OUTCOMES

Healthcare Outcomes \ Design Strategies or Environmental Interventions	Single-bed rooms	Access to daylight	Appropriate lighting	Views of nature	Family zone in patient rooms	Carpeting	Noise-reducing finishes	Ceiling lifts	Nursing floor layout	Decentralized supplies	Acuity-adaptable rooms
Reduced hospital-acquired infections	**										
Reduced medical errors	*		*				*				*
Reduced patient falls	*		*		*	*			*		*
Reduced pain		*	*	**			*				
Improved patient sleep	**	*	*				*				
Reduced patient stress	*	*	*	**	*		**				
Reduced depression		**	**	*	*						
Reduced length of stay		*	*	*							*
Improved patient privacy and confidentiality	**				*		*				
Improved communication with patients & family members	**				*		*				
Improved social support	*				*	*					
Increased patient satisfaction	**	*	*	*	*	*	*				
Decreased staff injuries								**			*
Decreased staff stress	*	*	*	*			*				
Increased staff effectiveness	*		*				*		*	*	*
Increased staff satisfaction	*	*	*	*			*				

* Indicates that a relationship between the specific design factor and healthcare outcome was indicated, directly or indirectly, by empirical studies reviewed in this report.

** Indicates that there is especially strong evidence (converging findings from multiple rigorous studies) indicating that a design intervention improves a healthcare outcome.

Figure 6 ***Table Summarizing General outcomes of EBD.***[73]

3.3. HEALTHCARE MODULES USING BIM

Once BIM is able to network facilities data with financial analysis of the hospital services, BIM has the potential to be used as a powerful tool for strategic planning.[74] A healthcare module is an assembly of organized components, based on healthcare department needs, contained together and maintaining an independent nature.[75] Each department becomes a module integrated into BIM which contains specific combinations of building components needed for the specialize activities. The decomposition of BIM modules entails breaking down the hierarchy of groups, prototypes, components and further if necessary to objects and artifacts for isolated

[73] Roger Ulrich et al., "A Review of the Research Literature on Evidence-Based Healthcare Design," *Healthcare Leadership*, no. 5, Evidence-Based Design Resources for Healthcare Executives (September 2008): 53.
[74] Matthew Kennedy, "Great Expectations: BIM for Healthcare," *The Samborn Report (Dimensions Newsletter)*, no. Summer 2008, http://www.ssoe.com/news/article2.aspx.
[75] George Miller et al., "Princeton University WordNet," lexical database, *Princeton University WordNet*, 2009, http://wordnet.princeton.edu/.

inquiry of design or redesign. The decomposition is based upon the teamwork of the components. Observing Figure 7 diagrams the possibilities for detaching information with the decomposition may pertain to further development or replacement of new and/or advanced information. Based on isolating the modules future development can be focused on independent areas of a healthcare facility, avoiding disruption or distraction relative to other spaces and supports scenario testing on various scales. Illicit investigations can be performed resulting in relevant information to the healthcare module. Instead of the current method of seeking researched knowledge in hopes of validating a design approach, BIM would reveal all sorts of correlations of the modules and provide the evidence to facilitate long term controlled studies of a given design project.[76] [77]

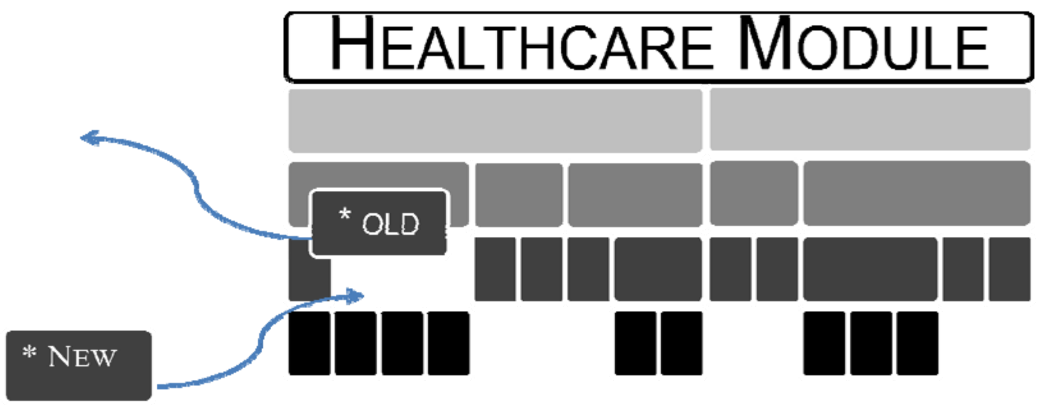

Figure 7 ***Diagram showing healthcare modules isolated for independent inquiry or new developments.***

3.4. MANAGING TOOLS, EQUIPMENT, AND OTHER DETAILS

Currently BIM has opened up opportunity to make collaboration more effective with providing real-time data exchanges, which are detailed scheduling, geometric coordination of healthcare equipment along with Mechanical, Electrical & Plumbing (MEP), and providing an explicit library of information for future strategic

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[76] Heng Li et al., “Integrating design and construction through virtual prototyping,” *Automation in Construction , Elsevier* 17, no. 8 (11, 2008): 915-922.
[77] Matthew Kennedy, “Great Expectations: BIM for Healthcare,” *The Samborn Report (Dimensions Newsletter)*, no. Summer 2008, http://www.ssoe.com/news/article2.aspx.

planning.[78] Risks and/or desired outcomes involved with managing the coordination of required equipment and tools and so forth are consolidates under the BIM process of design allowing preventative and assisting actions to be placed accordingly.

BIM used for the special characteristics of healthcare design also include accurate facility as-built information which can be critical to future renovations. BIM potentially reduces the need for full scale mock ups of patient rooms, surgical suites, etc. BIM is a repository of initial information provided by the client such as site information, area requirements and so forth which supports scenario testing for clients.[79] Creating a realistic scenario using BIM offers hard data information. This is useful for calculation and analysis to further develop healthy environments. Rather than creating a static full scale mock up, a much more flexible and transportable full scale virtual reality experience can be arranged by means of simulation provided through BIM.[80] [81] A comparison is depicted in Figure 8 below.

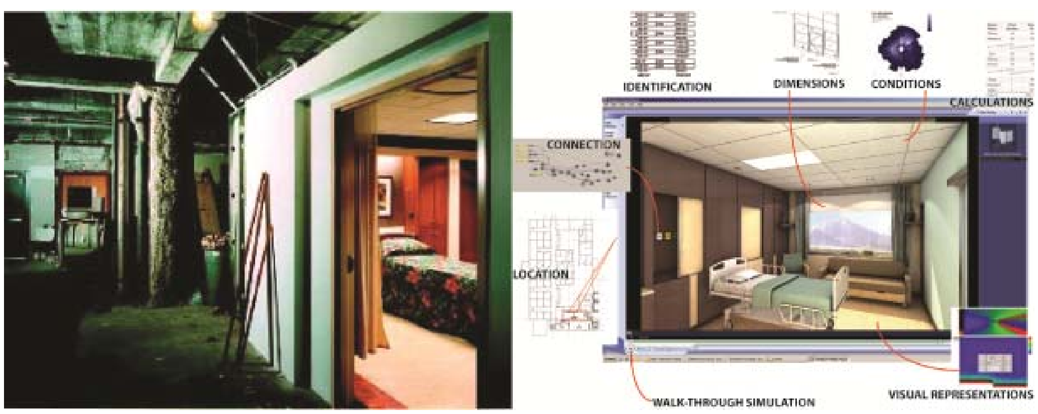

Figure 8 ***Full scale mock-up[82] & BIM simulation of patient room.***

[78] Russell Manning and John Messner, "Case Studies in BIM Implementation for Programming of Healthcare Facilities," *ITcon* 13 (July 2008): 446-457.
[79] Filiz Ozel, "Building Information Modeling for Healthcare Facilities" (Microsoft PowerPoint, Arizona State University - College of Design, May 19, 2008).
[80] Kathy Bell, "Mock-ups: Giving hospital clients the ultimate reality check," *Healthcare Design*, May 1, 2007, http://www.healthcaredesignmagazine.com.
[81] Phillip Dunston, Laura Arns, and James McGlothlin, "An Immersive Virtual Reality Mock-up for Design Review of Hospital Patient Rooms," in (presented at the 7th International Conference on Construction Applications of Virtual Reality, West Lafayette, IN: Purdue University, 2007).
[82] Kathy Bell, "Mock-ups: Giving hospital clients the ultimate reality check," *Healthcare Design*, May 1, 2007, http://www.healthcaredesignmagazine.com.

3.5. SUMMARY

BIM bridges between credible solid data information and the growth of EBD. Currently EBD is based on some collected amount of reliable case studies. Items that have been accepted as EBD are supported by these case studies or which some case studies are repeatedly used as the backing for EBD arguments. Healthcare facilities can be broken down into an understanding of healthcare modules – made up of related spatial and component needs. BIM can be implemented under the umbrella of these modules encouraging growth of reliable data supporting investigations of EBD. In all aspects of the healthcare environment, the BIM process has the capabilities of handling the various objects and specialized equipment which the healthcare profession is greatly dependent on. In all these areas BIM is attuned to the advancement of healthcare design.

4. BIM STRATEGIES

Three BIM strategies for healthcare design suggested in this paper include phasing, prototyping and application of baseline model. These are used for the analysis in the investigation of this D. Arch project.

First, most healthcare project are planned on a general ideal timeline, as the design team gains understanding about what the healthcare facility needs or what are unique issues, the assignments and the timeline are adjusted.[83] The importance of managing timeliness in healthcare design leads us to investigate the BIM phasing strategy. Evaluating and determining a set timeline and sequence of design events creates moments for regrouping and previewing. Thereby, having more accountability of completed work by phase rather than losing quality due to negligence, miscommunication or incomplete tasks while proceeding on in a project.[84] Secondly, layout of spatial relationships using prototypes allows the entire design team to begin coordinating. Using BIM prototypes brings in information for all participants on the project to begin observing what their responsibilities will entail on the project. The BIM prototypes forecast for the various members of the design team a large portion of their active role early on in the design process. Modifications and adjustments are made to the design while commencing the sequencing of phasing. Third, a strategy available by the completion of the project is baseline model – the BIM model serves as a foundation for future reference or a base for redesign, research, or other inquiries.[85]

[83] Glenn Ballard, "Improving Work Flow Reliability," in *IGLC-7* (presented at the Seventh Annual Conference of the International Group for Lean Construction, Berkeley, CA: University of California at Berkeley, 1999), 275-286, http://www.leanconstruction.org/pdf/Ballard.pdf.

[84] Glenn Ballard, "Can pull techniques be used in design management?," in (presented at the Conference on Concurrent Engineering in Construction, Helsinki, Finland: University of California at Berkeley, 1999), http://www.leanconstruction.org/pdf/PullinDesign.pdf.

[85] Orlando Maione, ed., "Open Building: A New Paradigm in Hospital Architecture," *AIA Academy Journal* (October 27, 2004), http://info.aia.org/journal_aah.cfm

4.1. PHASING

Phasing process with BIM provides the ability to forecast the development of on-going design project and its schedule. Each control system includes a "look-ahead window," which is part of a scheduled structure. Activities according to a master schedule are advanced through the look-ahead window. It gives a preview of the next phase before the phase commences. Figure 9 below diagrams the concept of phasing coordinated with a schedule on a timeline.

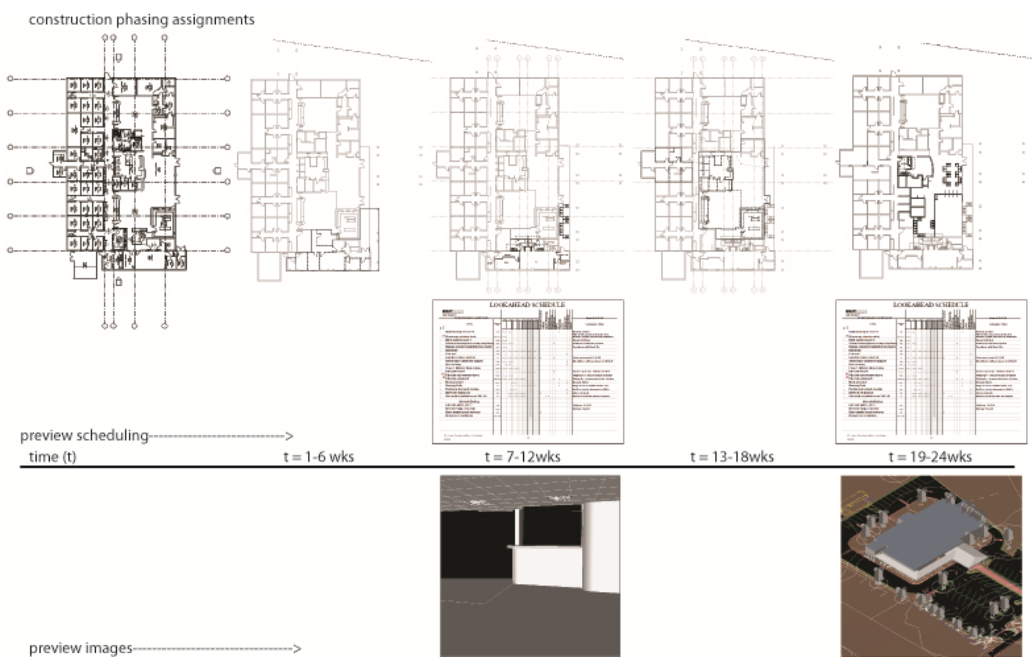

Figure 9 ***Overview diagram of forecasting/proceeding through BIM phasing.***

With the ability to look ahead, assignments are made according to the project units' capacity. Completing sound assignments maintains productivity through each phase of the project. The confidence comes from testing and then making operational by exploding the activities in accordance with the BIM model.[86] Using BIM to

[86] Glenn Ballard, "Improving Work Flow Reliability," in *IGLC-7* (presented at the Seventh Annual Conference of the International Group for Lean Construction, Berkeley, CA: University of California at Berkeley, 1999), 275-286, http://www.leanconstruction.org/pdf/Ballard.pdf.

evaluate phasing assignments before they are implemented supports necessary safety precautions. Previewing a phase helps prevent loose ends in design or scheduling before work is in motion. Whereas, in a traditional design process, most project teams attempt to adhere to the long-term master schedule very closely. Decision-making and maintaining consistent drawings throughout the duration of the project can become tedious and can take up a lot of time and effort. The traditional design process has less accountability on the project activities and causes less accuracy to drawings and production. Specifically, coordinating phases is challenging on healthcare projects due to complexity and liabilities that regularly drive the healthcare market. Challenges arise especially during construction and even more so on renovation projects. During healthcare renovation projects it is difficult building out interior spaces of an occupied medical facility, safety is a high priority and managing ingress/egress routes, infection control, required operational downtime and managing temporary spaces are example of some of the challenges.[87] For instance, a Magnetic Resonance Imaging (MRI) machine weighs approximately 30,000 pounds. Transporting this massive, expensive piece of healthcare equipment takes pre-planning. BIM can be used to find a precise date in the construction schedule and the optimal ingress route can be determined to ensure successful installation.[88] Phasing in BIM provides an integral and prompt coordination between systems within the design documentation. It greatly reduces the contingency of delivering design intent with unaddressed coordination issues between building systems. In the healthcare design industry most of the problems occur in MEP construction coordination. Its cost goes into, reaching numbers at about 45% - 55% of the total costs of the entire project.[89] Delineating design tasks in phases are enhanced remarkably when scheduled is supported by prototype modules reviewed throughout the later phases.

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[87] C.C. Sullivan, "Integrated BIM and Design Review for Safer, Better Buildings," *Architectural Record*, 2007, http://continuingeducation.construction.com/article.php?L=19&C=213.

[88] Graham Condit, "Complex projects call for virtual construction," *Seattle Daily Journal & DJC.COM*, no. Health Care Design & Construction - Special Section (November 16, 2006), http://www.djc.com/news/co/11184025.html.

[89] C.C. Sullivan, "Integrated BIM and Design Review for Safer, Better Buildings," *Architectural Record*, 2007, http://continuingeducation.construction.com/article.php?L=19&C=213.

4.2. PROTOTYPING

Defining a prototype starts from understanding a category. A category is made up of families and within families there are types. Each time a type may exist in a family, singularly or multiple times, each is known as an instance.[90] This relationship exists on different scales but regardless of scale, the relationship is consistent. In the case of healthcare design, the category is healthcare and the families are specialized spaces such as the exam room, patient room, etc. Types of exam rooms are general purpose examination room, special purpose examination room, observation room, and treatment room; from these prototypes are generated. As prototypes are formulated, they are assigned to projects and the option to refine prototypes is available. Prototyping in BIM maintains certain levels of organized information preventing confusion or inconsistencies during the design process. It makes information accessible after the completion. The primary computer application utilized for this case study is Autodesk Revit 2010. In its data base, Autodesk Revit stores the reference to *Design and Construction of Health Care Facilities* by the Facility Guidelines Institute (FGI) and the American Institute of Architects (AIA). The reference supports foundational parameters for the development of healthcare design. It provides closely review the development of selected spaces in this project.

Furthermore, parameters according to these guidelines are implemented through simulation function in the evolving process of prototype. In this process, most basic attributes are accounted for and included into an initial prototype. Further detail to the initial prototype relative to any project becomes a new level of prototype. As illustrated in Figure 10. A later stage of an evolving prototype results in a physical product. Variances and errors are likely to occur during and after the physical construction of the building. The reality of a building is reviewed and taken into account to consider for further development of BIM prototypes.

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[90] Revit. Architecture 2010 Imperial Tutorials. 2009. *Autodesk*, San Rafael, CA, Autodesk, Inc.

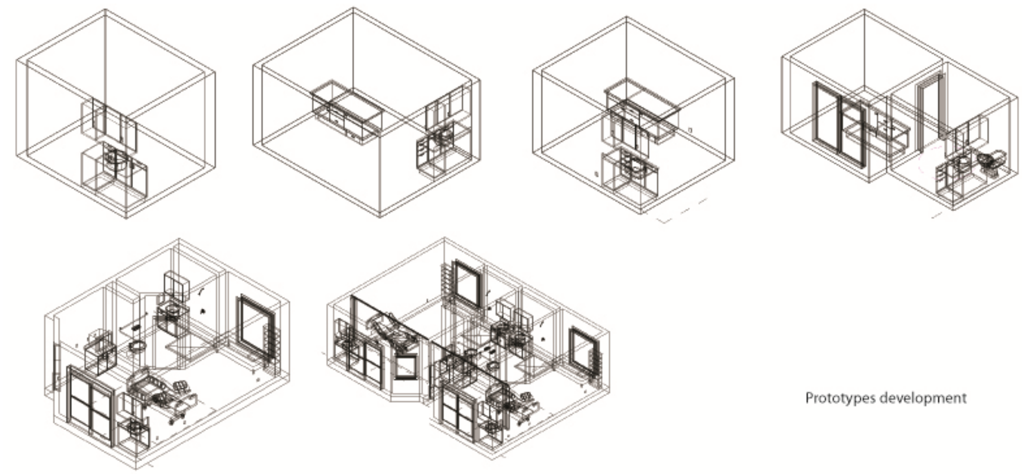

Figure 10 ***Diagram depicting iterations of BIM prototyping.***

4.3. BASELINE MODEL

A baseline model is a post-construction BIM model that was originally developed during the design of the building as a new construction project or initially integrated into a project of a building as a renovation/redesign project. This model contains the previous design work and provides accurate information regarding the building's functions and attributes. Figure 11 illustrates a visual comparison between a redesign project using tradition methods and the one with a BIM baseline model. By the end of a project in a traditional design process, several connections of information are lost or kept within the boundaries of specialized groups who worked on the project due to the absence of a baseline model. However, a baseline model in BIM becomes the basis of the well coordinated building information model through various design phases. Passing on a baseline model for future design work or renovations prevents uncertainty regarding the current state of the building. At the completion of the design project the BIM model serves as a resource for future inquiry. Referring to the BIM model as the baseline model for any future alterations occurring later has made-ready information to be extracted from the model and a record of ongoing work. The BIM baseline model becomes the key to the whole BIM process with consolidating large amounts of 3D data from different applications into one model.[91]

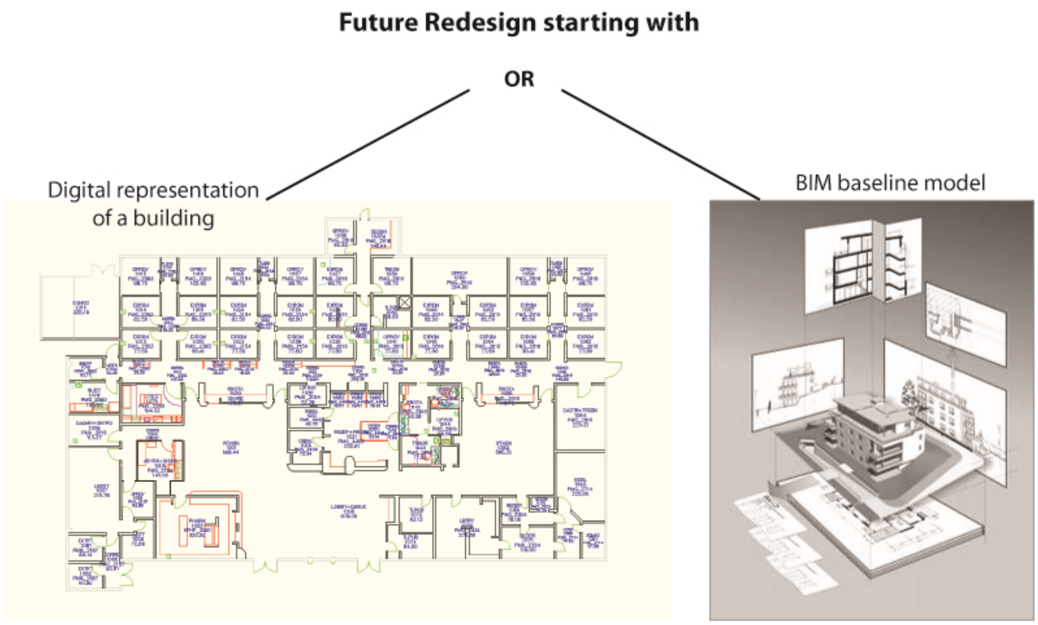

Figure 11 *Comparison between digital representation and BIM baseline model.*

4.4. SUMMARY

While there are other directions which can be explored the chosen strategies for implementation of the BIM process of design in this project is by using phasing, prototyping and baseline model.

[91] C.C. Sullivan, "Integrated BIM and Design Review for Safer, Better Buildings," *Architectural Record*, 2007, http://continuingeducation.construction.com/article.php?L=19&C=213.

5. CASE STUDY

In this section, the direction and goals are conveyed by communicating the functional, spatial and other programmatic requirements particularly to a design project using a traditional design process. Communicating these programmatic elements is significant as it is adapted to the case study using a BIM process of design. Comparisons between using the traditional process and a BIM process to the pursue design goals are made based on the outcomes through a case study (Figure 12).

Figure 12 ***Images of the case study for the renovation of a primary healthcare facility.***

5.1 PROGRAM

The case study is to renovate a primary healthcare clinic, one story building concrete and steel framed structure. Originally constructed in the 1960s with minor additions and remodels within the last twenty years, this building has approximately 8900gsf of existing structure, housing facilities which provide basic examinations, imaging, pharmacy, laboratory, and minor surgical needs. The beginning phase is considered new construction adding to a total of 14,650gsf by the end of the design project.

In order to achieve different goals for the redesign of this building various engineering disciplines encompass civil, landscape, structural, mechanical, plumbing and electrical. Project goals are to 1) design an attractive facility that provides for quality patient care and an environment that promotes healing. 2) Provide functional space relationships that will optimize available space and provide for operational efficiencies and convenience for patients. 3) Also design facilities adequately for healthcare services that meet current and anticipated needs. 4) Maintain compliance with the current Life Safety and Code requirements and 5) design for flexibility in adapting to future and changing needs of the health care delivery system and work environment that promotes staff satisfaction.

While this building is undergoing renovation the design is managed in construction phases throughout the existing structure using AutoCAD 2D applications. The comparison comes from using a customized BIM process to perform the same tasks involved in the renovation project. Reflecting on the comparison between the traditional process and using BIM reveals the effectiveness of how information is managed. BIM is employed as a liaison in the design process for developing optimized BIM strategies in healthcare design.

Meetings were held to review and establish the functional and space program for the clinic. Managers and client user groups met to establish functional space needs, functional relationships and preferred adjacencies. Safety and security issues were identified and addressed in the development of the design.

Space programming and the conceptual floor plan were developed by referencing the comments made in meetings with the User Group. The User Group is made up of key personnel including the Clinic Chief, Internal Medicine Chief, Clinic Supervisor, Clinic Registered Nurse (RN) and Clinic Pediatrician. The department's preferred functional flows and current space deficiencies were analyzed based on: room type and sizes, preferred room adjacencies, space deficiencies, what works and does not work, current and projected needs and consolidation of shared work areas.

There are two parts to this project, allowing for some temporary transitional spaces for staff and continuity of operation during the renovation of the clinic spaces.

Part one consists of Phase 1:

This includes a new Staff Lounge and lanai looking onto a cascading water feature and landscaping and a new walking path with integrated fitness stations.

The basis of design for the Staff Lounge is a one-story structure, light gauge steel framing and wood trusses, concrete slab on grade, exterior plaster and standing metal seam roofing. It entails sliding glass doors comprised of three walls that opens up into an outdoor patio with views a tropically landscaped garden and cascading water feature. The exterior elevation of the structure is intended to feel open airy and with glass sliding doors that create transparency. Finishes are resilient flooring, paint and an exposed ceiling.

Part two consists of the remaining Phases 2-4:

This includes renovation of the existing clinic spaces and new finishes throughout the entire clinic. Within the renovation there is sequencing of work while the clinic continues to be operational.

The basis of design for part two revolves around the renovation of the clinic (pertaining to internal medicine, & Obstetrics/Pediatrics). This entails, remodeling and expanding the pharmacy and adding walk up windows, providing outdoor seating at the main entrance, the specialty clinic with separate entrance, remodeling reception and add registration kiosks. Part two also entails renovation for team rooms, exam rooms, shared injection/allergy room, behavior health room, social worker room, triage, work-up stations and offices; plus, completely replacing both the existing ceiling system and the existing finish flooring and then also adding guardrails at the curb along the existing entrance.

Architectural design references for these two phases are:

- AIA Guidelines for Design and Construction of Hospitals and Healthcare Facilities – 2006 Edition
- NFPA Life Safety Code 101 – 2003 Edition
- Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities
- 2003 International Building Code with local amendments
- Chapter 93, Broad Service Hospitals of the Administrative Rules
- City and County Zoning Codes

While there are other engineering disciplines involved in the design project. The case study is pursued from an architectural perspective. Specific elements for comparison are based on this perspective. These goals reflect the original project team's plans using traditional methods of design. Selective goals are adopted into this case study for comparison between using a traditional process of design and a BIM process of design.

5.2 SUMMARY

The basis behind this case study is that is a healthcare facility undergoing one phase identified as new construction and a number of following phases identified as renovations. All the phases of construction occur with the services of the healthcare facility remaining active. While the actual project is performed using a traditional design process and 2D applications (Figure 13 – 17) the case study is performed using a BIM process as a means for contrasting the result and findings between the two, specifically from the architectural standpoint.

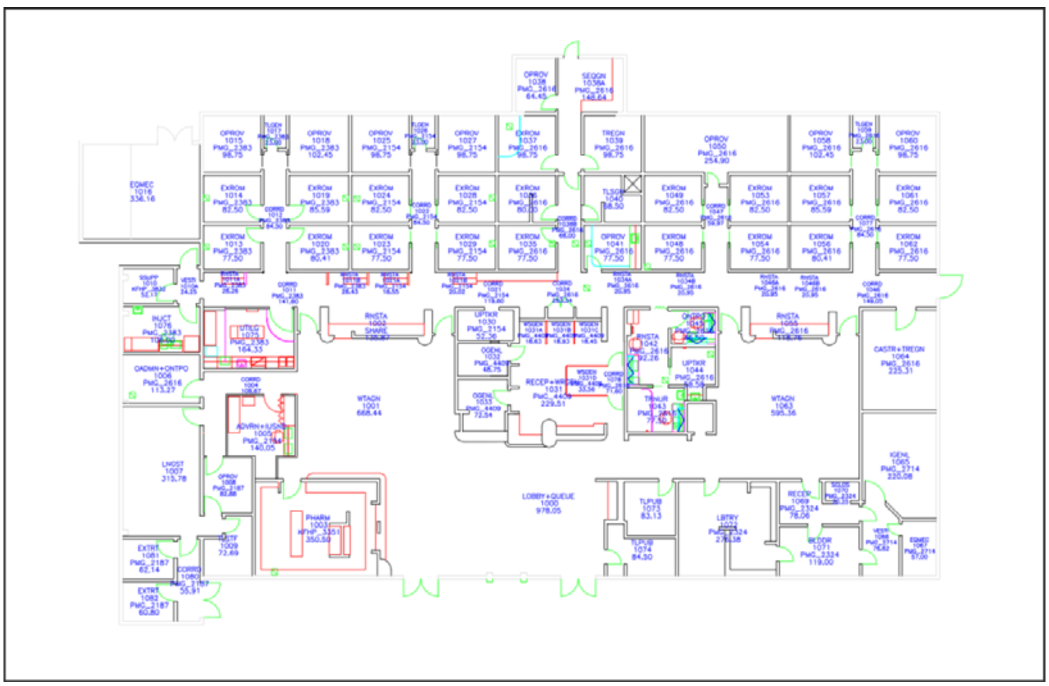

Figure 13 ***2D CAD existing design.***

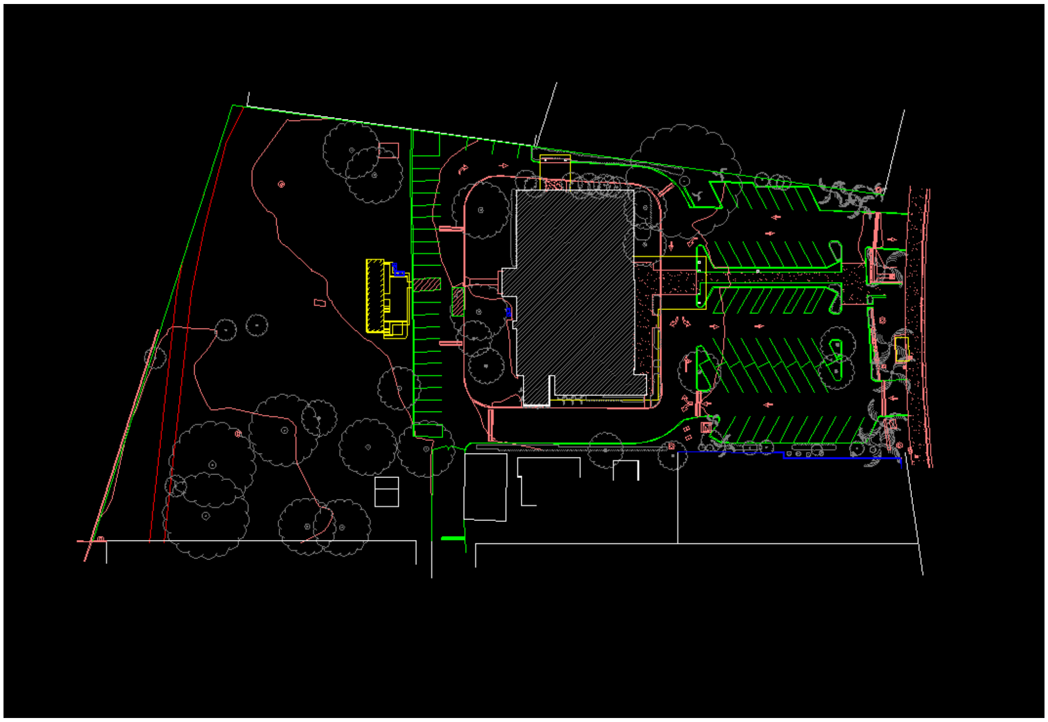

Figure 14 ***2D site plan*****.**

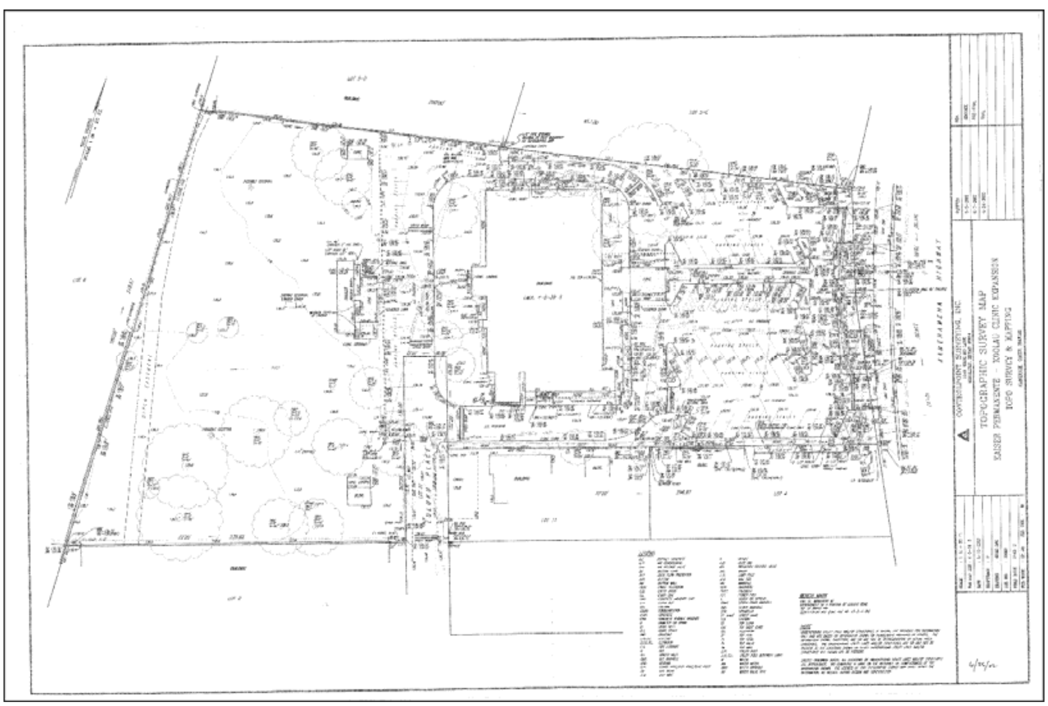

Figure 15 ***Scanned 2D topographic site plan*****.**

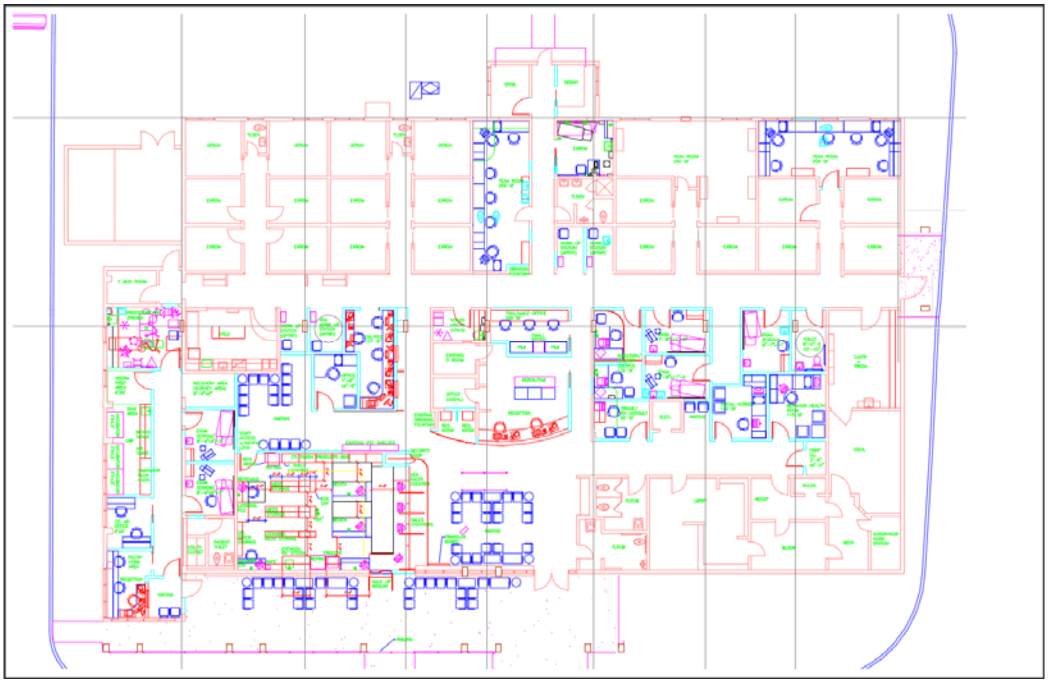

Figure 16 ***Developing design using a traditional approach*.**

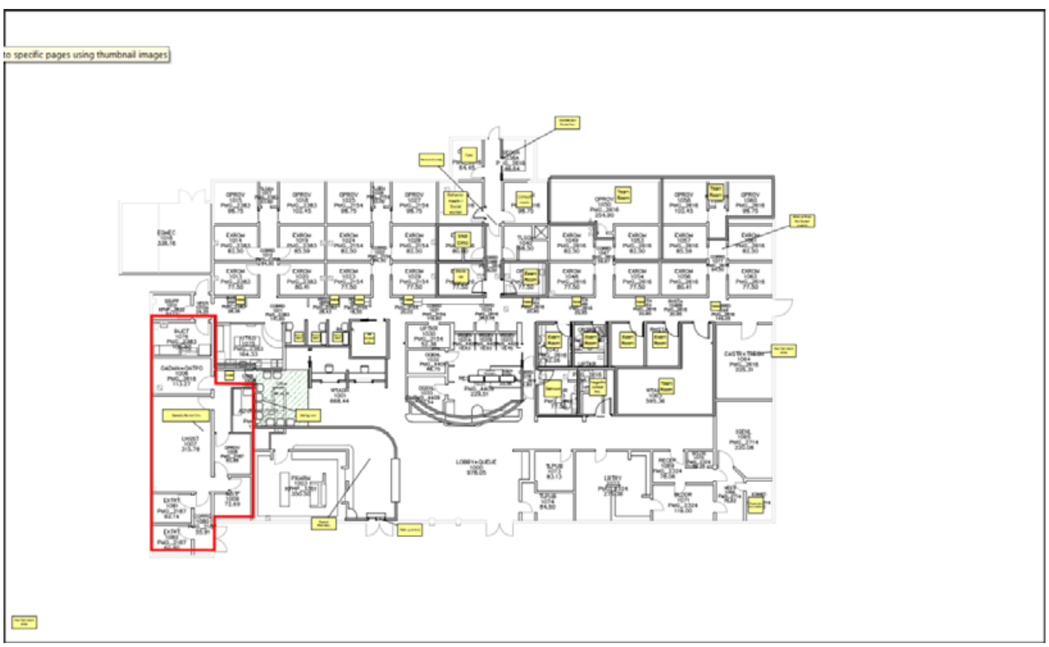

Figure 17 ***Changes during design process*.**

6. DESIGN MODELS

In this project the utilization of BIM in healthcare design is explored through a few strategies: phasing, prototyping, and application of baseline modeling. These strategies are applied to a case study with is set up as an adopted scenario to an actual project which is processing through design with a more traditional approach. The processes of using these strategies are exemplified in this section. For each strategy a number of examples can be shared but this project only a couple of examples exploring the support of BIM to healthcare design are emphasized.

6.1 PHASING: TEMPORARY BARRIERS AND EGRESS ROUTES

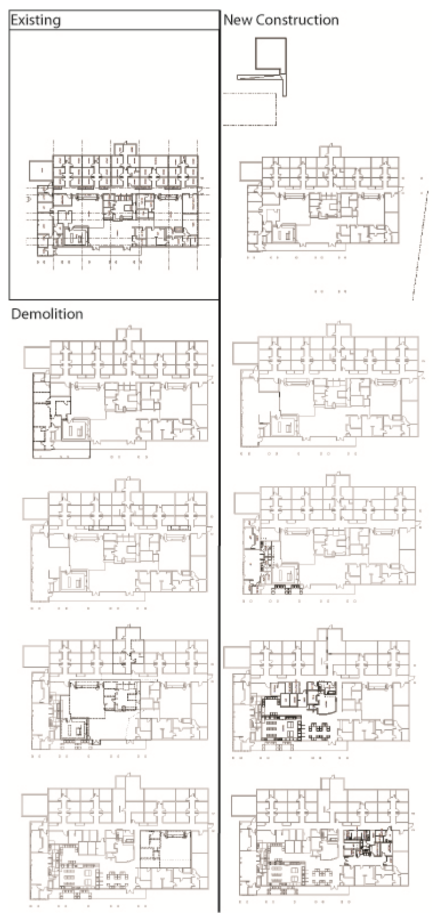

Figure 18 ***The case study project adopted into a BIM process had one new construction phase and four remaining renovation phases.***

BIM involves integrating information to and from different sources, tools and applications. Phasing the project (Figure 18) produced in Revit initially will be outreached to other management information tools. This is an example of BIM processing in phasing. The sharing of information between modeling a design and managing the phases of the project are observed in this process. Figures 19 – 28 reveal phases of the project in order.

Within Revit alone, the project has been phased and all drawings and components are simultaneously coordinated based on the treatment of each phase. The order of demolition and new construction mimic reality. For example if a wall was demolished in a previous phase, it will not be available for alteration in later phases within the design project. Plainly, this reflects reality.

By initially phasing the design project, the information pertaining to each phase is maintained throughout different levels of coordination. Extracting information is manageable by phasing out the design. Upon coordinating activities, objects, equipment and spatial requirements the necessary information is contained during each phase. Also, scenario testing for each phase is also possible with extracting individual phases for analysis. Having the ability to maintain the entirety of the project but also work in isolated areas according to a scheduled timeframe allows for monitoring a range of items and activities which go on during the design and construction process.

In the case study for the renovation of a healthcare facility monitoring the construction phases are very important since the services of the existing structure are to remain active. Having the ability to anticipate necessary means for safety can be more accurately accounted for by phasing out the design in this BIM process. Two critical aspects of safety in an active healthcare facility during construction is 1) monitoring temporary barriers which contain the atmosphere during construction from leaking into active healthcare spaces which can be detrimental to the wellness of patients and healthcare professionals and 2) managing the appropriate temporary egress routes during the renovation.

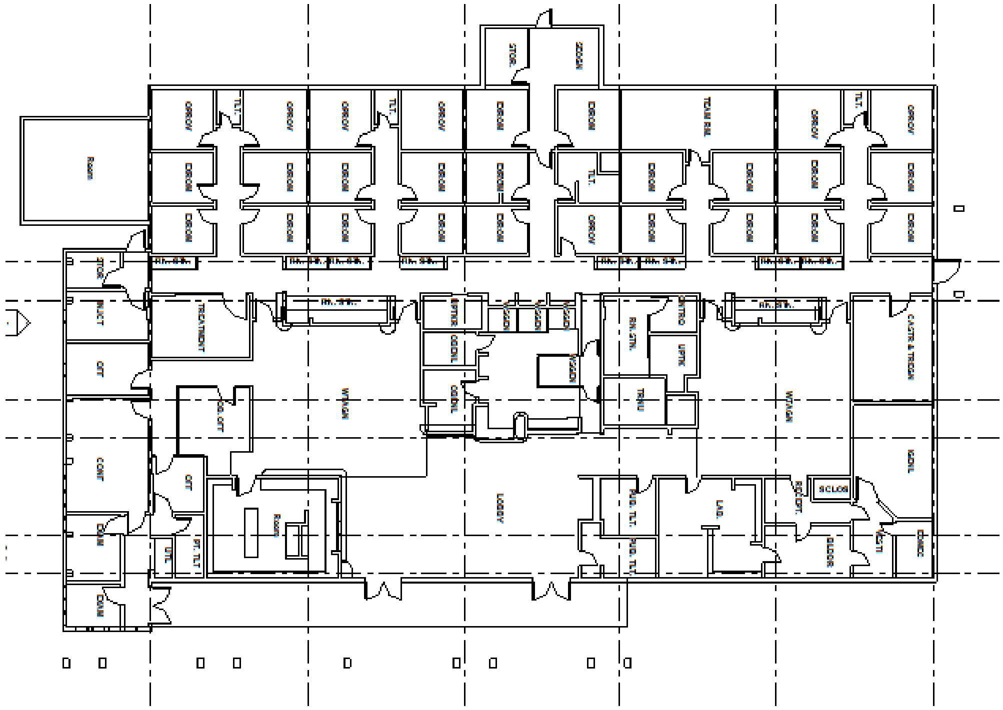

Figure 19 *Existing phase*.

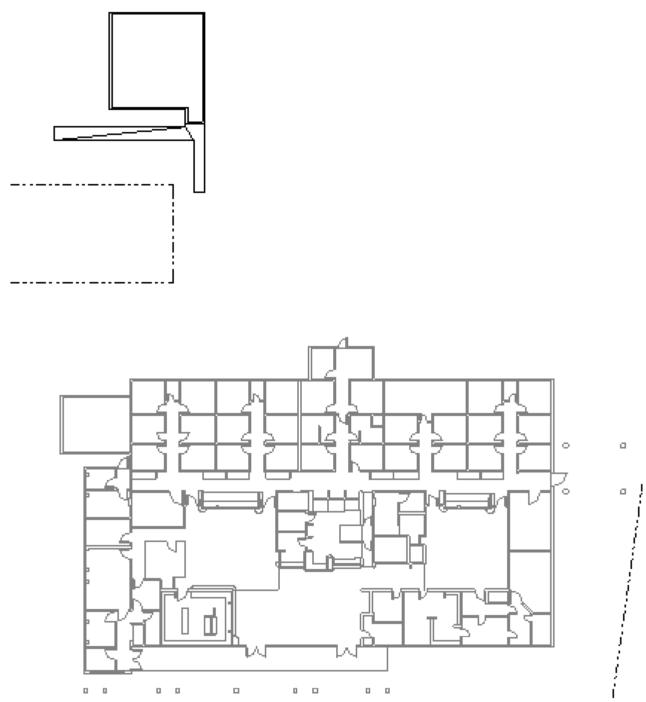

Figure 20 *Phase 1 – new construction*.

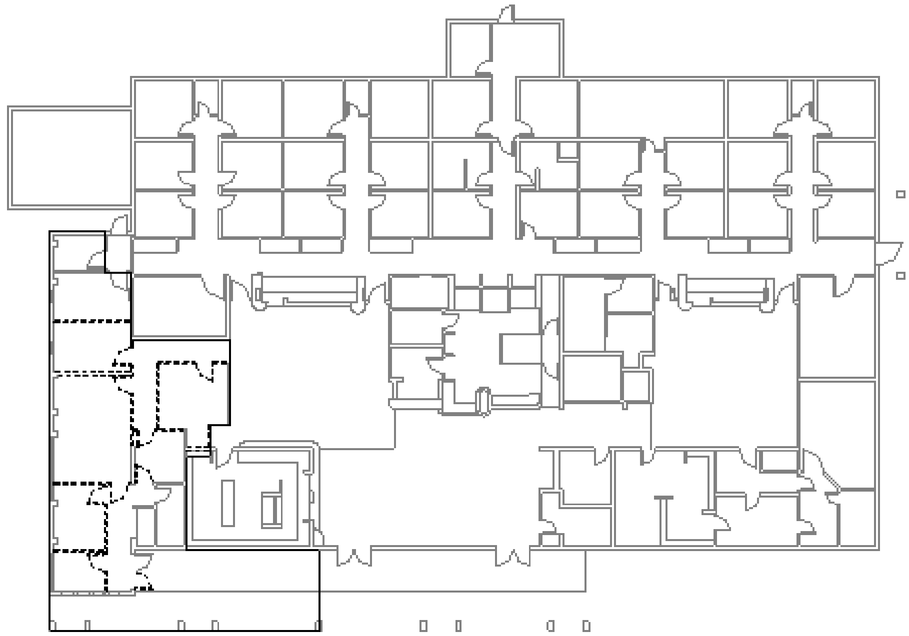

Figure 21 ***Phase 2 – demolition.***

Figure 22 ***Phase 2 – temporary barriers.***

Figure 23 ***Phase 2 – continued demolition*****.**

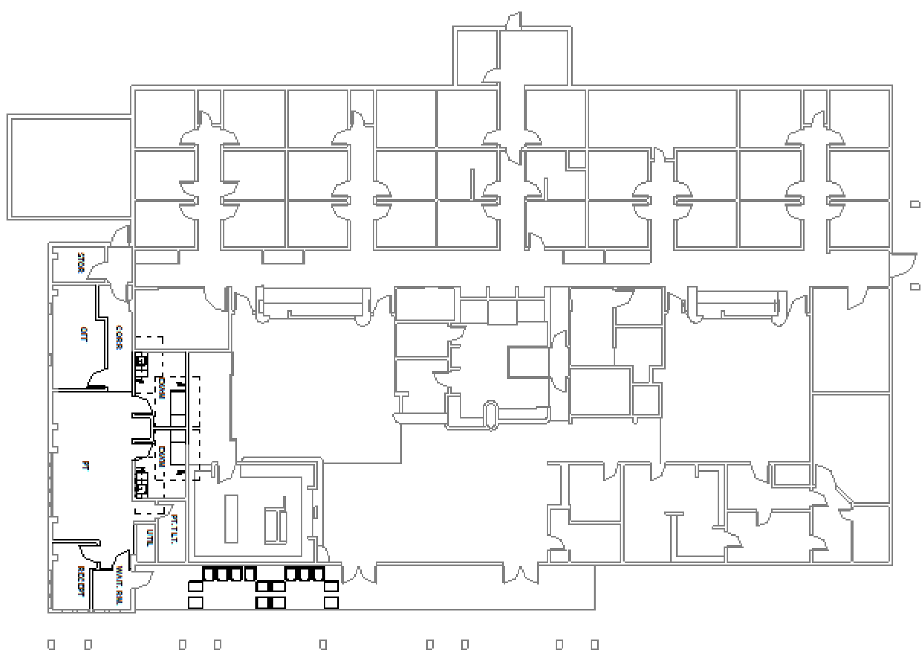

Figure 24 ***Phase 2 – new construction*****.**

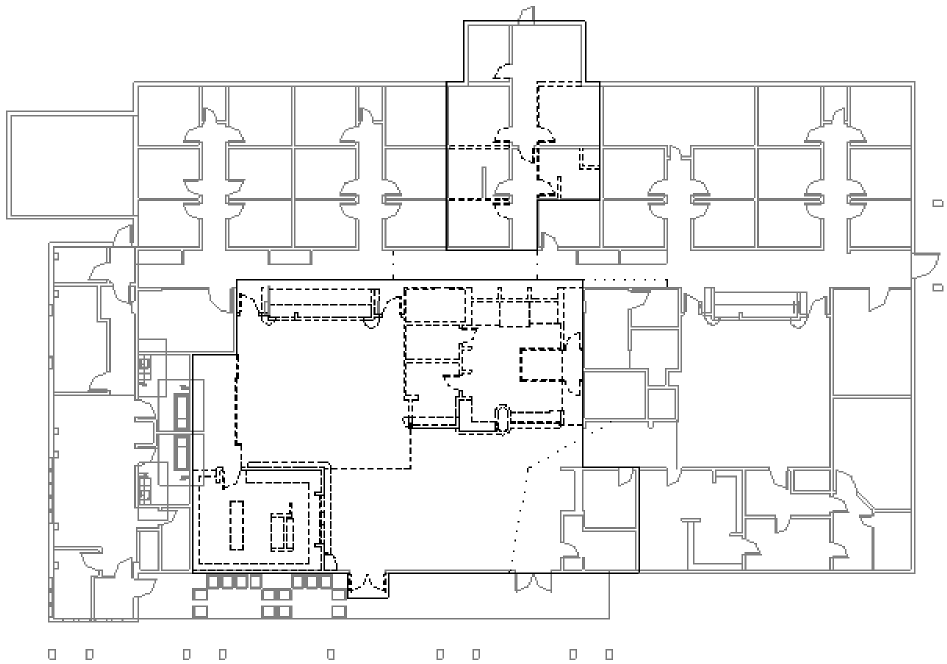

Figure 25 ***Phase 3 – demolition*.**

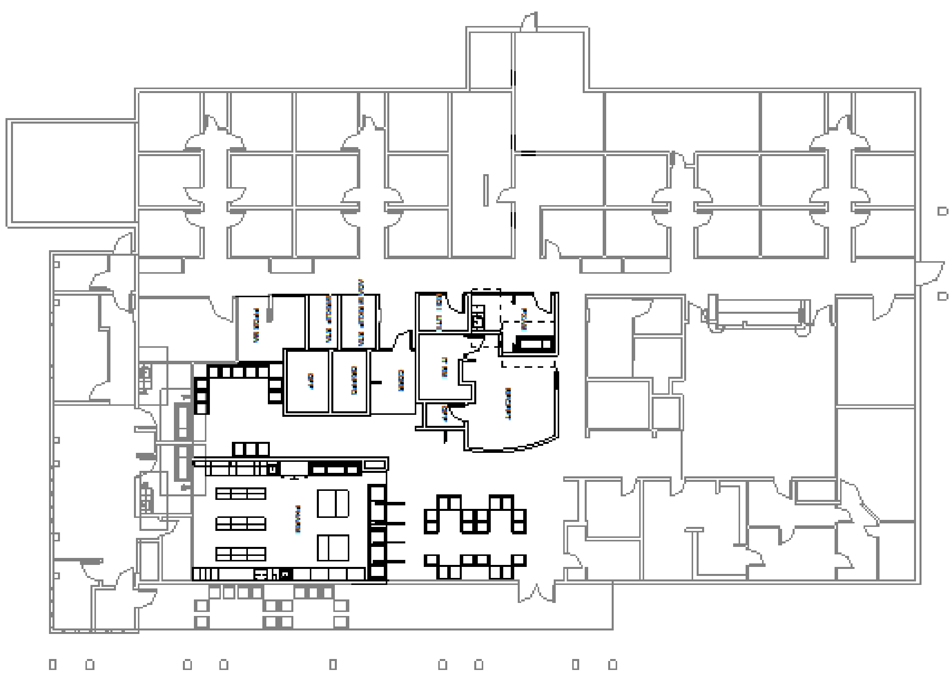

Figure 26 ***Phase 3 – new construction*.**

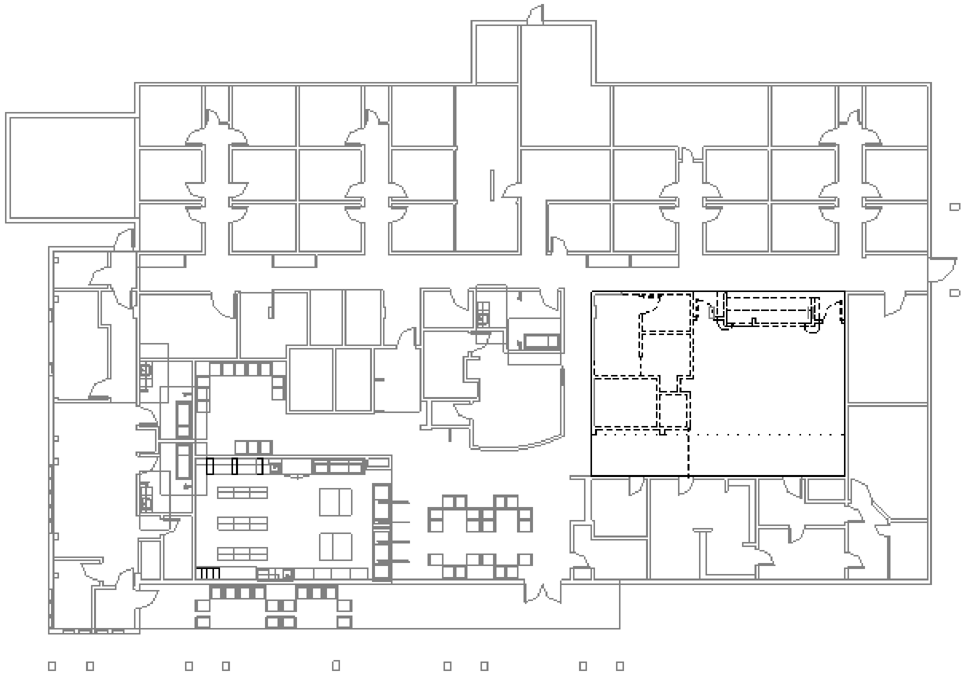

Figure 27 ***Phase 4 – demolition.***

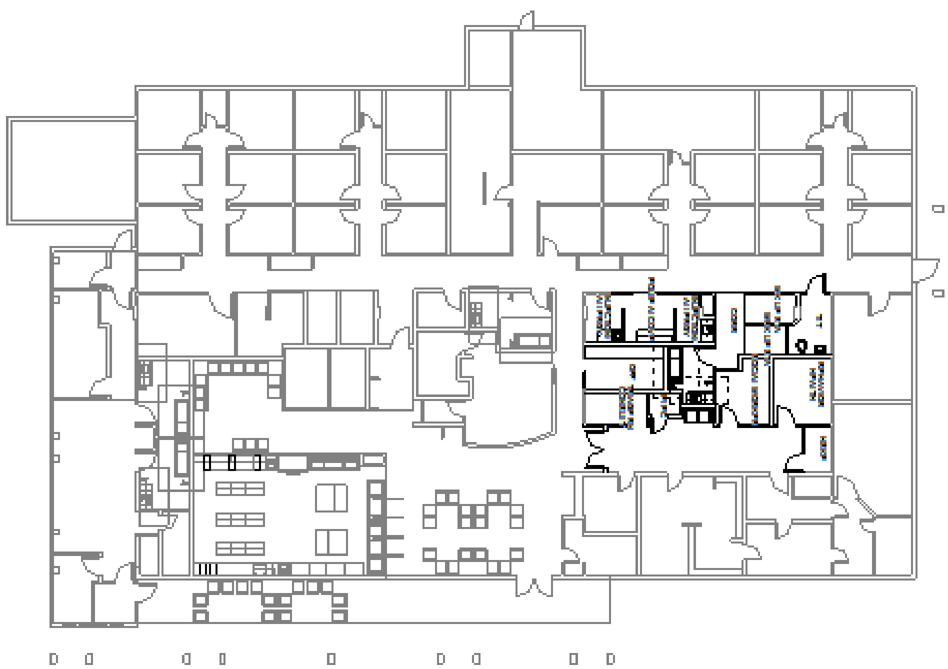

Figure 28 ***Phase 4 – new construction.***

6.1.1. Monitoring temporary barriers

As the design of the healthcare facility develops in Revit, phases are created to communicate existing, temporary barriers, demolition and new construction. Organizing the priorities during the construction process through phases establishes increased accountability during the actual design process. Using a BIM process of design allows building professions to schedule in advance the desired outcomes within a time frame. Figure 29 diagrams the phasing and scheduling relationship. Previewing the phases enables the healthcare professionals to gain awareness early on of the procedure that will be occurring throughout the duration of the construction process. This is important in this case study because the clinic will still be actively providing their healthcare services during the construction process. Additionally when phasing the planned and actual outcomes, the correlating phases can be cross-referenced. The capacity set for the next phase can be based on the actual outcome of previous.

Revit as a BIM tool can outreach and communicate with other helpful BIM tools. Phasing is based on how the information is prioritized and arranged to communicate with each other. For this example, monitoring barriers such as the demolition, temporary and new construction is highlighted and also preventative action barriers based as an organizing priority in the design of this healthcare facility. Barriers are preventative actions against unwanted circumstances accessing uncontaminated areas. Every phase carries a separate view focusing on each of those categories. Other BIM management tools such as Navisworks cooperates with BIM scheduling tools such as MS Project, Primavera, ASTA Power Project, etc. and other BIM tools involve environmental analysis, all of which have the ability to communicate and transfer information from the Revit project. This sharing of information allows the ability to schedule the project on a time line and check the planned portions against the actual production.

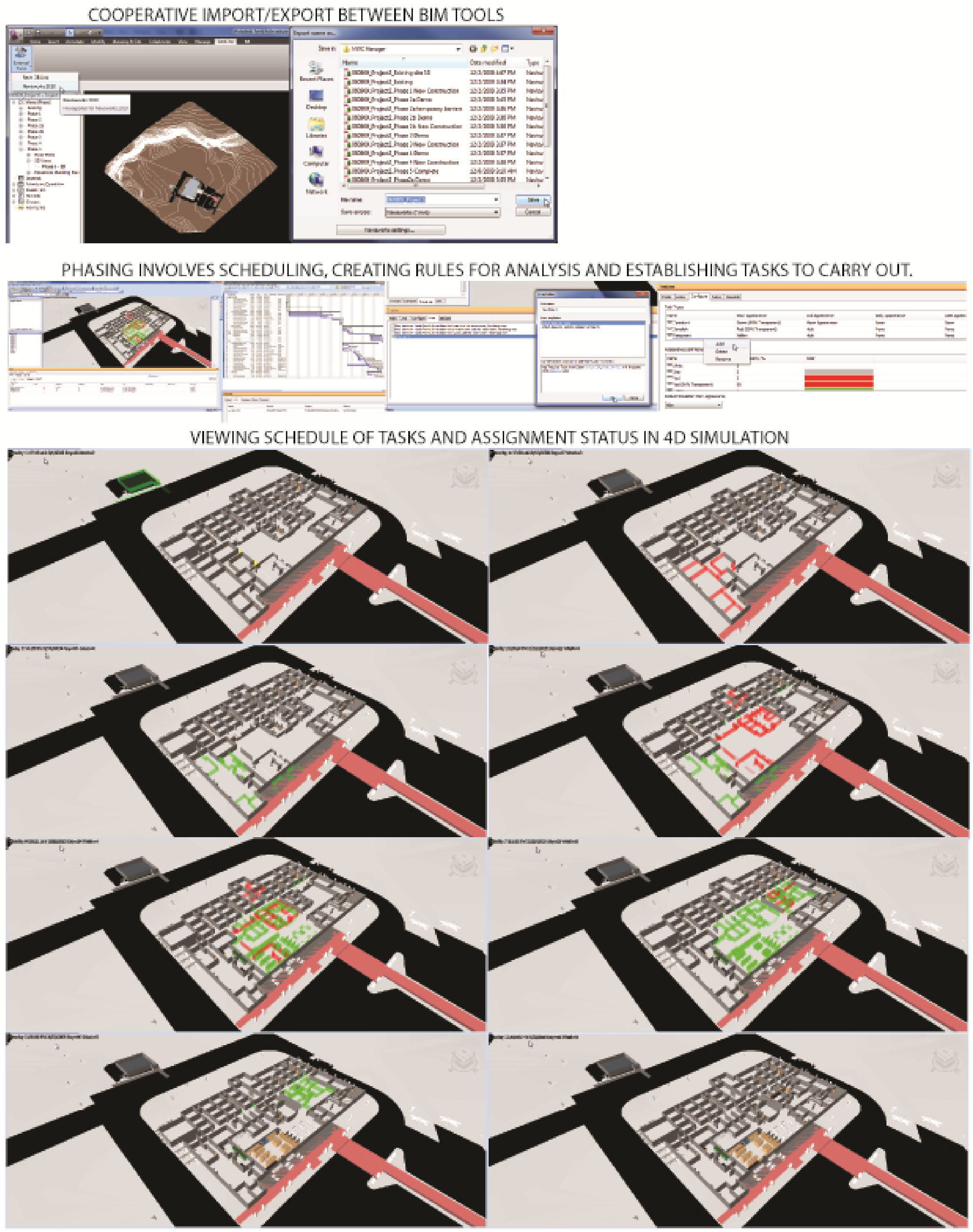

Figure 29 ***Phasing scheduled tasks communicate status and capacity of production by comparison of planned and actual outcomes.***

The Revit project is a repository of information regarding the design which allows for scenario testing, data inquiries and real time visualizations of the design process. By scheduling the appropriate temporary barriers it decreases the vulnerability of active spaces during renovation. Also in partnership with temporary barriers, the use of high efficiency particulate air (HEPA) filters has been identified as necessary for use on healthcare renovation projects. Along with temporary barriers, these pieces of equipment which prevent the air quality from digressing can be scheduled in the needed locations. A healthcare facility is considered a protective environment. Guidelines under the Center for Disease Control (CDC) recommend design that includes infiltration and ventilation control, directional airflow and pressure control.[92] With reference to the specific phase of the design, space can undergo analyzing with Computational Fluid Dynamics (CFD) modeling and thereby supports decisions concerning if the number of HEPA filters being used is adequate and if they are set in appropriate locations.[93] Figure 30 diagrams the possibility of the case study project pharmacy space with its associated massing in association with the image of a previous lab pharmacy which underwent CFD modeling analysis. The opportunity to include CFD modeling is definite in the BIM process of design. Data from an additional analysis such as this also opens large contributions of information to further EBD. These are examples of phasing in different types of information or analysis options. Overall, phases are based on priorities to building design and construction assignments set on a timeline. Decisions on how these items are prioritized in the phasing of the design project will enable useful information for the design and construction of a healthcare facility.

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[92] "Meeting Healthcare Guidelines with CFD Analysis," *Where Design Meets Excellence*, 2006, http://www.dfwcgi.com/services/Studies/CFDforHealthcare.htm.

[93] Bob Hansen, "New health care design guidelines emphasize infection control measures," *Austin Business Journal*, no. February (2005), http://austin.bizjournals.com/austin/stories/2005/02/14/focus5.html.

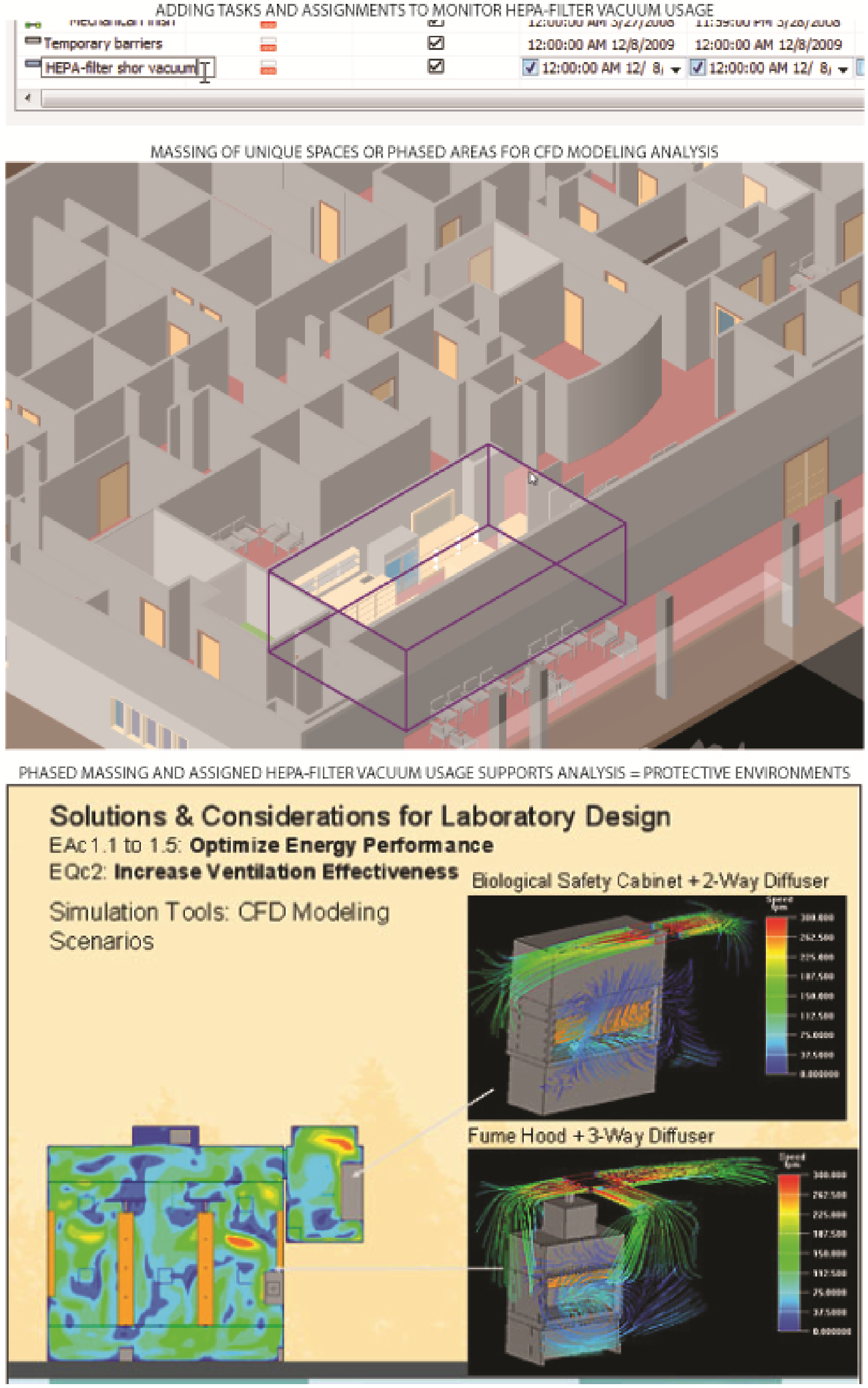


Figure 30 *Phasing Pharmacy space relationship to example Laboratory CFD modeling analysis.*

6.1.2. Managing temporary egress routes during renovation

Communicating egress can be done in different ways, during phases in construction and egress path is created as a family (Figure 31) and can be assigned to the different phases (Figure 32); it is a component so the egress path can be treated as existing, demolition and/or new construction. Assigning proper egress for each phase remains coordinated on the timeline that each phase is developed for. In the same way, phasing out the egress paths can be coordinated with scheduling and checking for proper treatment for temporary egress paths during construction can be reviewed in advance and checked against the plan for egress with the actual outcome of the construction process. Aside from coordinating drawings and scheduling, visual aids for understanding egress can be reviewed with animations generated from the BIM model. The safety of users within active areas of the healthcare facility is high priority.

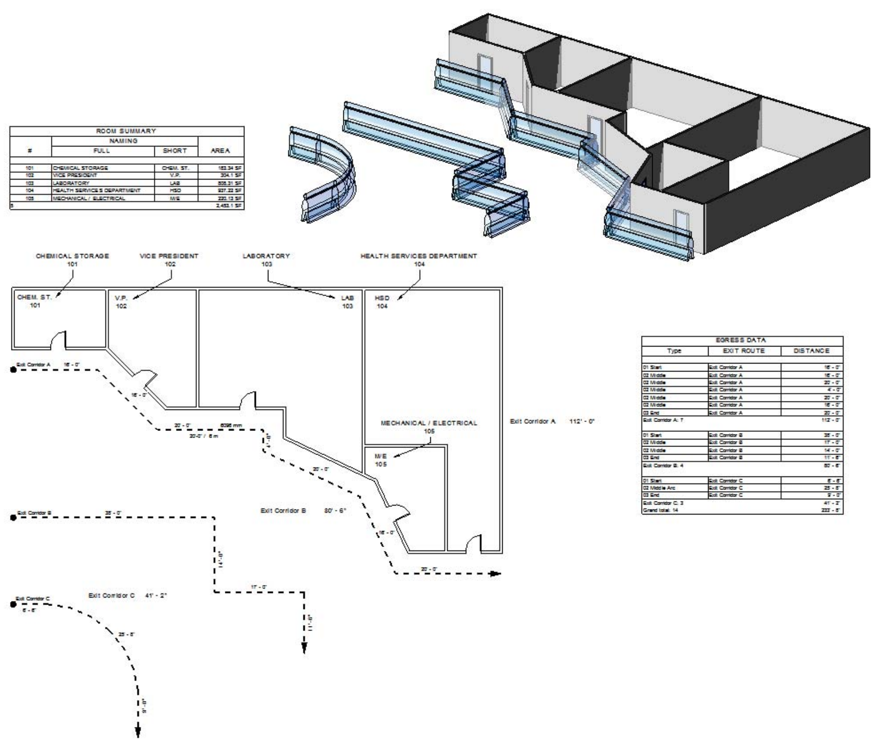


Figure 31 ***BIM coordination of egress routes along with schedules.***[94]

[94] Steve Stafford, "Revit OpEd," Blogger, *Room Name - Full or Abbreviation*, December 15, 2008, http://revitoped.blogspot.com/2008/12/room-name-full-or-abbreviation.html.

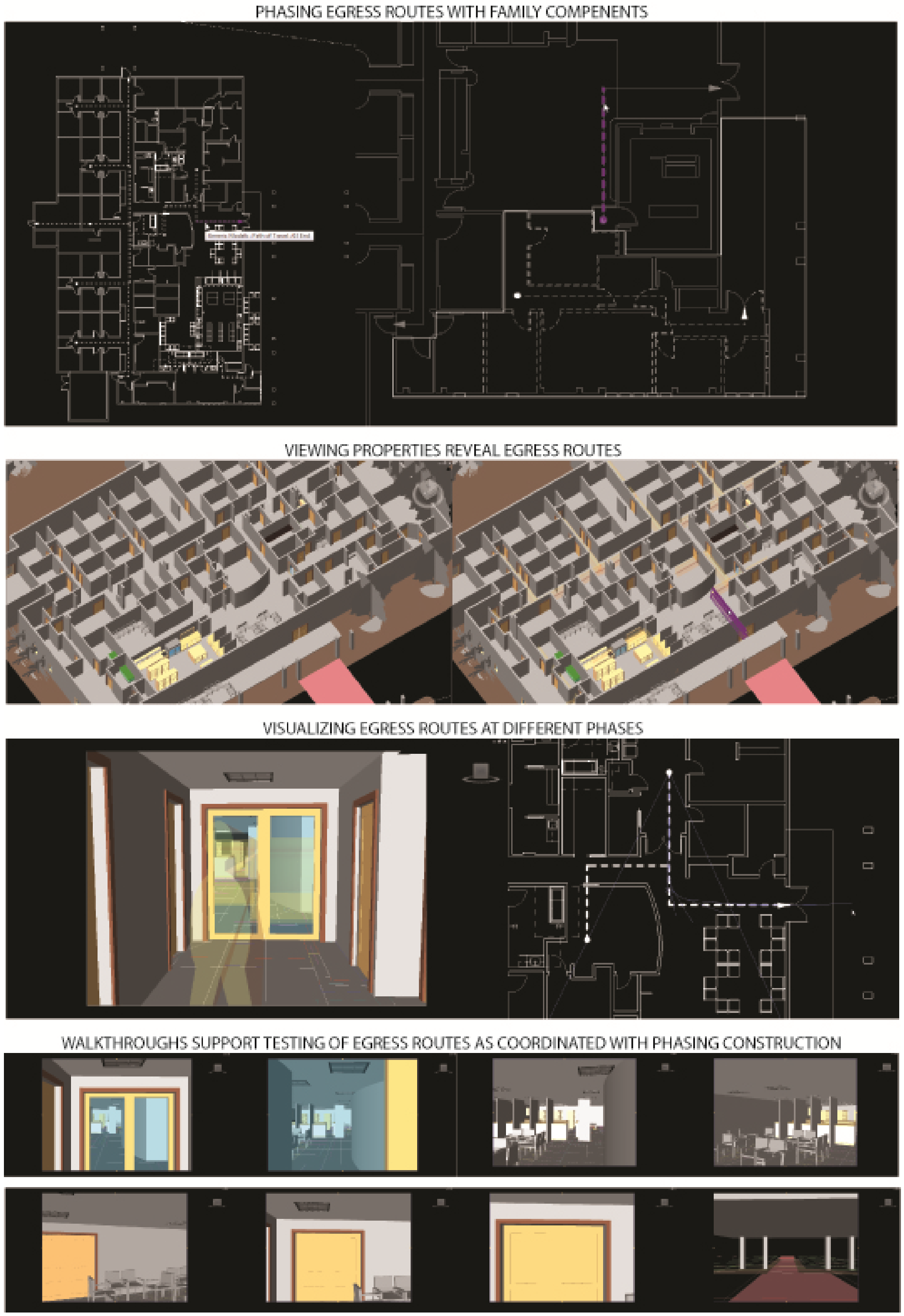
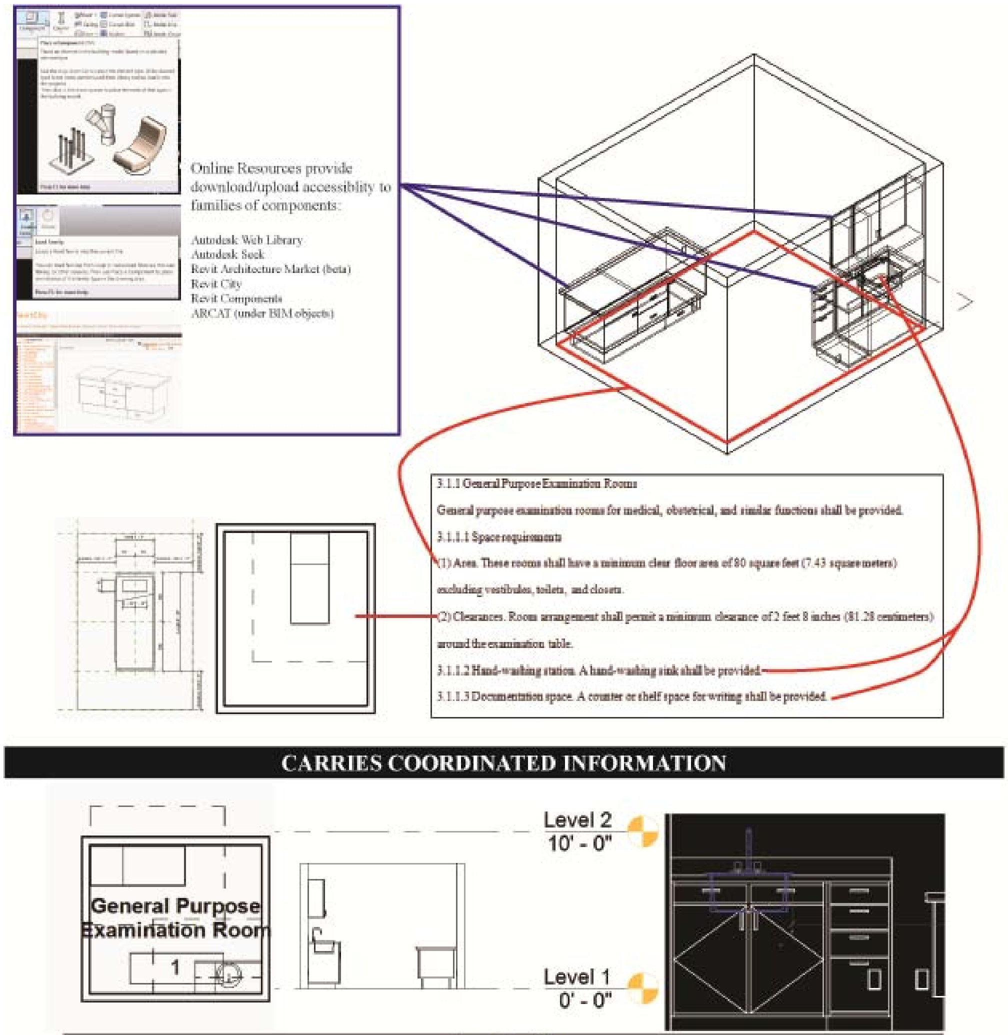


Figure 32 ***Establishing temporary egress routes during renovation. Coordinated and visualizing the egress routes according to phases.***

6.2 PROTOTYPING: RULES AND INTEGRATION

This investigation involved setting up rules and spatial needs to create a prototype for a specific healthcare space. A diagram shown in Figure 33 shows the relationship between the rules, prototype and output data. Achieving prototypes which meet foundational requirements for healthcare design is based on various guidelines established for the design and construction of healthcare facilities. Upon creating a prototype, the following action is integrating the prototype into a project. In doing so, some manipulation to prototypes may be necessary depending on the specific project. Some spaces within a healthcare facility are repeated in layout whereas some only exist in a facility as a single standalone space. Some examples of repeated spaces may be exam rooms, patient rooms, and/or nursing stations and so forth. Contrary to this as an example would be a pharmacy which is only necessary as a single entity in a healthcare facility. Two example prototypes (Figures 34 and 35) are explored and used to communicate the setup of a healthcare prototype and the integration of a healthcare prototype into a project. Setting up a healthcare prototype is explained through the example of the General Examination Room Prototype. Integration of prototypes into a project is exemplified using a pharmacy prototype. Exploring the setup for an exam room prototype and integration of a pharmacy prototype into a project contributes various findings.



Room Schedule

Number	Name	Area	Unbounded	Volume	Comments
1	General Purpose Examination Room	105 SF	10' - 0"	1045.00 CF	min. 80sf clear floor area

Space Allocation Schedule

Count	Type	Room Floor Area SF	Component Floor Area SF	Clear Floor Area SF	Description
1	36" 2 door cabinet	105	6 SF	99	
1	Doctors_Large_Exam_Table_2781_e1	105	15 SF	90	
2			21 SF		

Figure 33 ***BIM Strategy: Prototyping.***

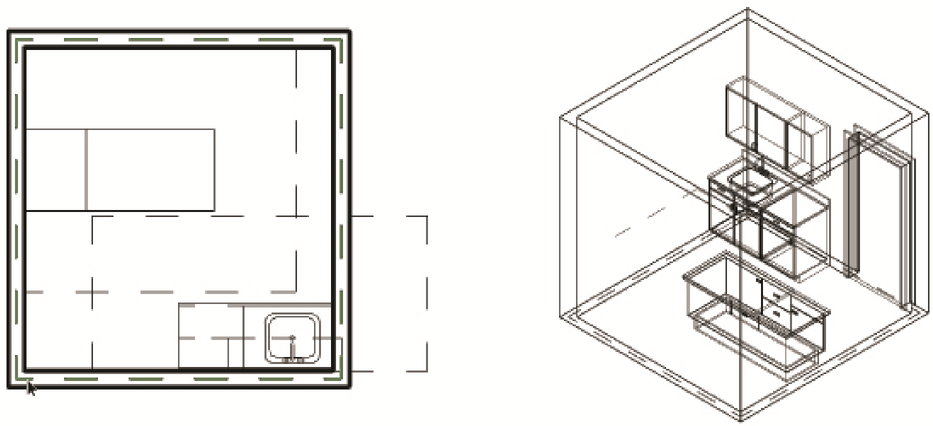


Figure 34 ***General Examination Room Prototype*.**

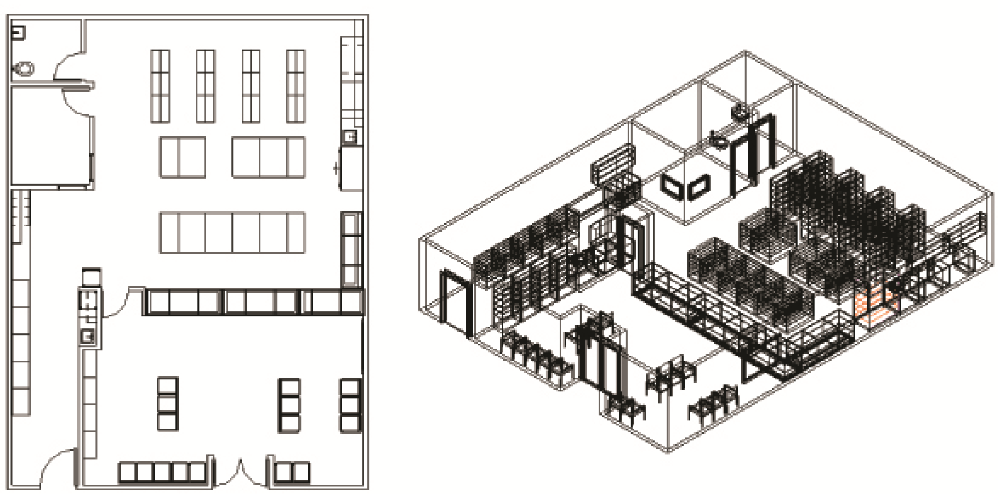


Figure 35 ***Pharmacy Prototype*.**

6.2.1. Rules – setup BIM prototype parameters

Prototyping begins with reference to Guidelines for Design and Construction of Health Care Facilities, the National BIM Standards, and a few other reliable reference materials.

A general examination room is the most basic of health care spaces. To start a new BIM prototype project this general examination room is chosen to explain the process. The strategy for initially setting up a prototype for a particular healthcare space is to begin with the necessary space and the primary use of the room including the most important component that will be used. These prototypes will be referencing the 2006 Guidelines for Design and Construction of Health Care Facilities. These guidelines include the following (Figure 36):

3.1.1 General Purpose Examination Rooms

General purpose examination rooms for medical, obstetrical, and similar functions shall be provided.

3.1.1.1 Space requirements

(1) Area. These rooms shall have a minimum clear floor area of 80 square feet (7.43 square meters) excluding vestibules, toilets, and closets.

(2) Clearances. Room arrangement shall permit a minimum clearance of 2 feet 8 inches (81.28 centimeters) around the examination table.

3.1.1.2 Hand-washing station. A hand-washing sink shall be provided.

3.1.1.3 Documentation space. A counter or shelf space for writing shall be provided.

Figure 36 ***list from Guidelines for Design and Construction of Health Care Facilities 2006.***

Based on the recommendation of these guidelines a few actions were decided upon for starting a new BIM prototype project which include 1) setting parameters for a Desired Area, 2) obtaining appropriate components, 3) setting parameters for clearances and 4) setting schedule parameters. The actions for prototyping in relation to the guidelines are highlighted in Figure 37.

3.1.1 General Purpose Examination Rooms General purpose examination rooms for medical, obstetrical, and similar functions shall be provided.	
3.1.1.1 Space requirements	→Setting schedule parameters
(1) Area. These rooms shall have a minimum clear floor area of 80 square feet (7.43 square meters) excluding vestibules, toilets, and closets.	→Setting parameters for a Desired Area
(2) Clearances. Room arrangement shall permit a minimum clearance of 2 feet 8 inches (81.28 centimeters) around the examination table.	→ Setting parameters for Clearances
3.1.1.2 Hand-washing station. A hand-washing sink shall be provided.	→Obtaining appropriate components
3.1.1.3 Documentation space. A counter or shelf space for writing shall be provided.	→Obtaining appropriate components

Figure 37 ***Parameters selected for prototypes based on the relationship to the healthcare guidelines.***

The exam room has guidelines concerning the floor area. An exam room prototype is a typical example or basis for further design and development in a healthcare design project. Using a conceptual model will help to explain the process for creating constraints for the prototype. In order to setup a prototype understanding the relationship of parameters to their respective objects, components and/or families is necessary. Using Reference planes, Dimension parameters and Formulas a Desired Area can be defined within Revit.

The first action is setting parameters for a Desired Area. For this portion in explaining the start of a prototype the first action is to set parameters for a Desired Area. This is initial action is chosen because different healthcare spaces have guidelines regarding minimum floor area. Defining a Desired Area parameter supports the necessary guidelines set for healthcare spaces. In order to conceptualize the process of setting up parameters in Revit as a generic action the explanation will be based on a mass object representing a room space. As illustrated in Figure 37. In creating a mass family it allows for the process of laying out parameters based on reference object, line, and/or space. By creating reference lines on a level one reference (XY coordinates plane), Revit can manage the calculated space. Naming the Reference lines (Top, Bottom, Left, Right) is important for mapping out the direction and behavior of the object which these parameters are being defined for. Equalizing the distances of the references lines from the (0, 0) XY coordinates supports the mass to be proportional. Drawing the lines so they make an orthogonal rectangle allows visualization of a box shape. Then a rectangle is drawn within those reference lines boundaries by selecting the reference plane datum option. Dimensioning 2 orthogonal sides of the reference box opens the option to make a new dimension type parameter and name the sides according – length and width. Then by selecting the Family Types option, the parameters appear. By selecting "Add" under the parameter section create a "Desired Area" dimension parameter. Since these parameters are named and associated to spatial value, formulas can be created to make mathematical relationship between the sides of the box. For example, (Figure 38) "Width = Desired Area / Length." Following these same steps for creating height in an elevation view is another optional dimension option. When finished to see the results of the automatic dimensional relationship developed based on setting parameters can be view by creating a form from the reference box on the reference plane. Locking the surface planes of the box to the reference plane set with parameters will hold the object to the relationship of parameters that were created. In the 3D view selecting the move option the automatic response of the length and width of the box object reflect the relationship made be creating the parameters when dragged in different directions.

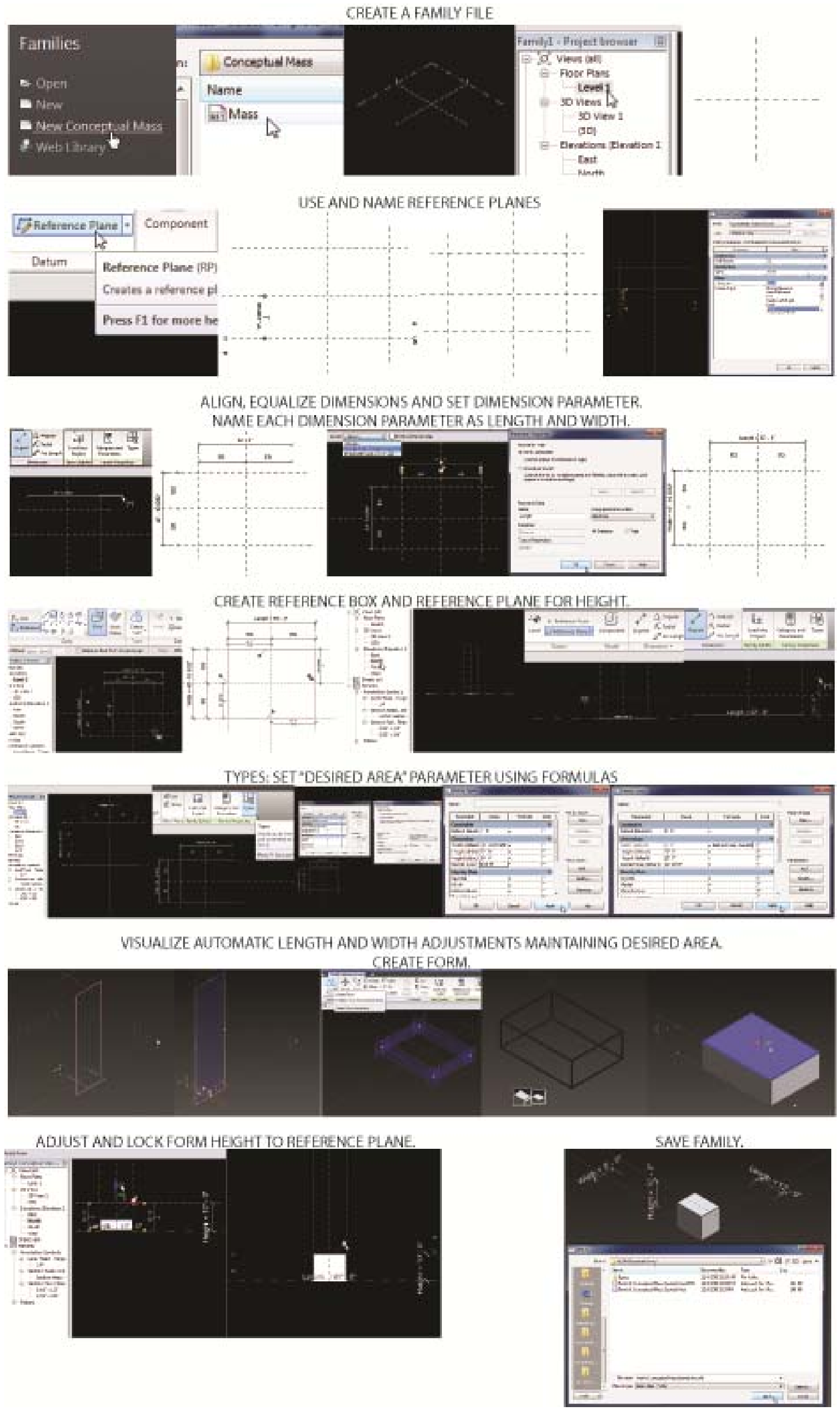


Figure 38 ***Arranging and setting parameters for Desired Area for the exam room prototype.***

The second action in starting a new prototype based on the guidelines shown in Figure 36 is obtaining appropriate components for BIM prototyping. Realizing the primary components of the healthcare space for which a prototype is being created is preliminary. Referring to appropriate guidelines, primary components required in an exam room is the exam table, a hand-washing station and documentation space. Gathering these important components can be done using the given library within Revit or from other resources. However, the only standard components made available for easy access at the beginning of new project are most commonly wall, door, window, components. For the exam room an exam bed/table is needed which is not made available at first. Loading components from the Revit Application – Library is one way to find the component need. These components are typically known as "Families." A fundamental aspect of the BIM process is the quality and quantity of information included in a model, so in selecting component families it is critical to select components which are informed based on reliable sources as well.

This exam room needs a different exam table rather than the one available through the Revit Library. There are online resources where Families of components can be downloaded, uploaded, for a price or for free – available through open source forums. Some examples are: Autodesk Web Library, Autodesk Seek, Revit Architecture Market (beta), Revit City, Revit Components, and ARCAT (under BIM Objects), etc. Commonly used is the Sweet Catalog which now includes a BIM collection. Illustrated in Figure 38 are two options of exam tables available through an open source site, called Revit City. In setting up this prototype the component Doctors_Large_Exam_Table_2781 (top option in Figure 39) is selected. Saving the components to a file library in the computer is then also available for future use as well.

Figure 39 *Components from Revit City can be downloaded for this exam room prototype.*

Beginning this prototype, basic components used are chosen according to the guidelines. After identifying basic components we also are aware of the guidelines which pertain to features within the exam room. Clearances are necessary around any furniture in an exam room. For example, according to guidelines the minimum clearance for the exam table is 2 feet 8 inches around it. Taking into account the requirements for a hand-washing station and documentation space, selecting a sink component and counter top component aim to fulfill these guidelines. Selected components for developing this general examination room prototype are illustrated in Figure 40. When a project is saved or a component is saved as a family, this is the beginning of a file library. This will be the start of a "Healthcare Design Library."

A third action for starting this prototype is setting parameters for clearance. Guidelines require features within healthcare spaces to maintain particular clearances. Every prototype space has a location with a folder containing the project files and component files. While the components are saved to specific project locations creating a General Healthcare Design Library for Components is appropriate for future use.

Figure 41 shows by selecting the family component exam table for editing, reference lines can be created around the form of the exam table in the reference plane view. Draw reference lines parallel to each edge of the exam table. With these reference lines dimensions can be placed between the exam table edge and its correlating parallel reference line. Selecting all the drawn dimensions a new dimension type parameter is created. By inputting the distance 2'-8" each reference line with a dimension parameter associated to it will automatically adjust to that distance, thus setting the requirements for any furniture necessary for the general examination room prototype. By drawing hidden lines with the "select line" option the clearance for the component can be visible in a project. Now when components carry this parameter the clearance recommended can be visualized during the design process. Also the option to turn off the visibility of the represented clearance can be done through the properties of the exam table family component.

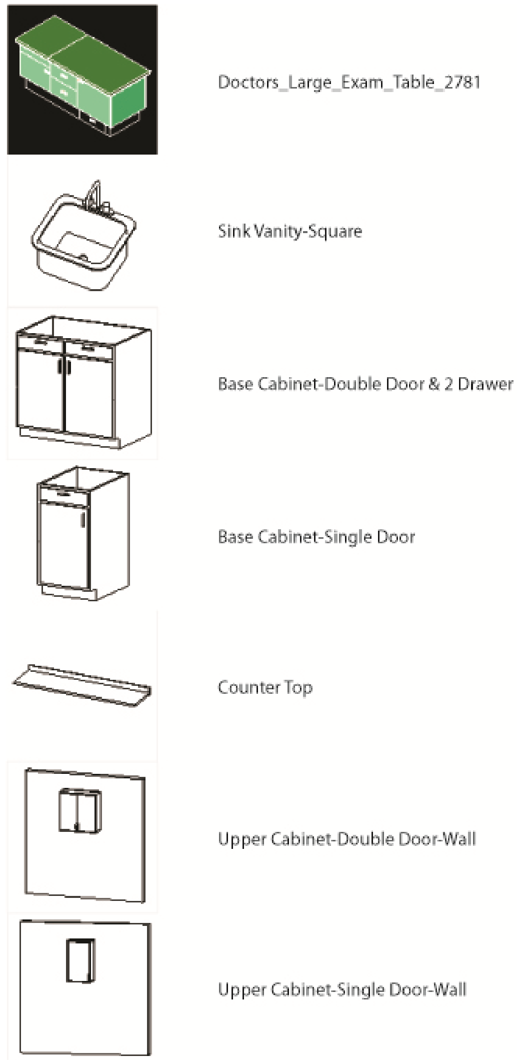


Figure 40 ***Components utilized for starting an exam room prototype.***

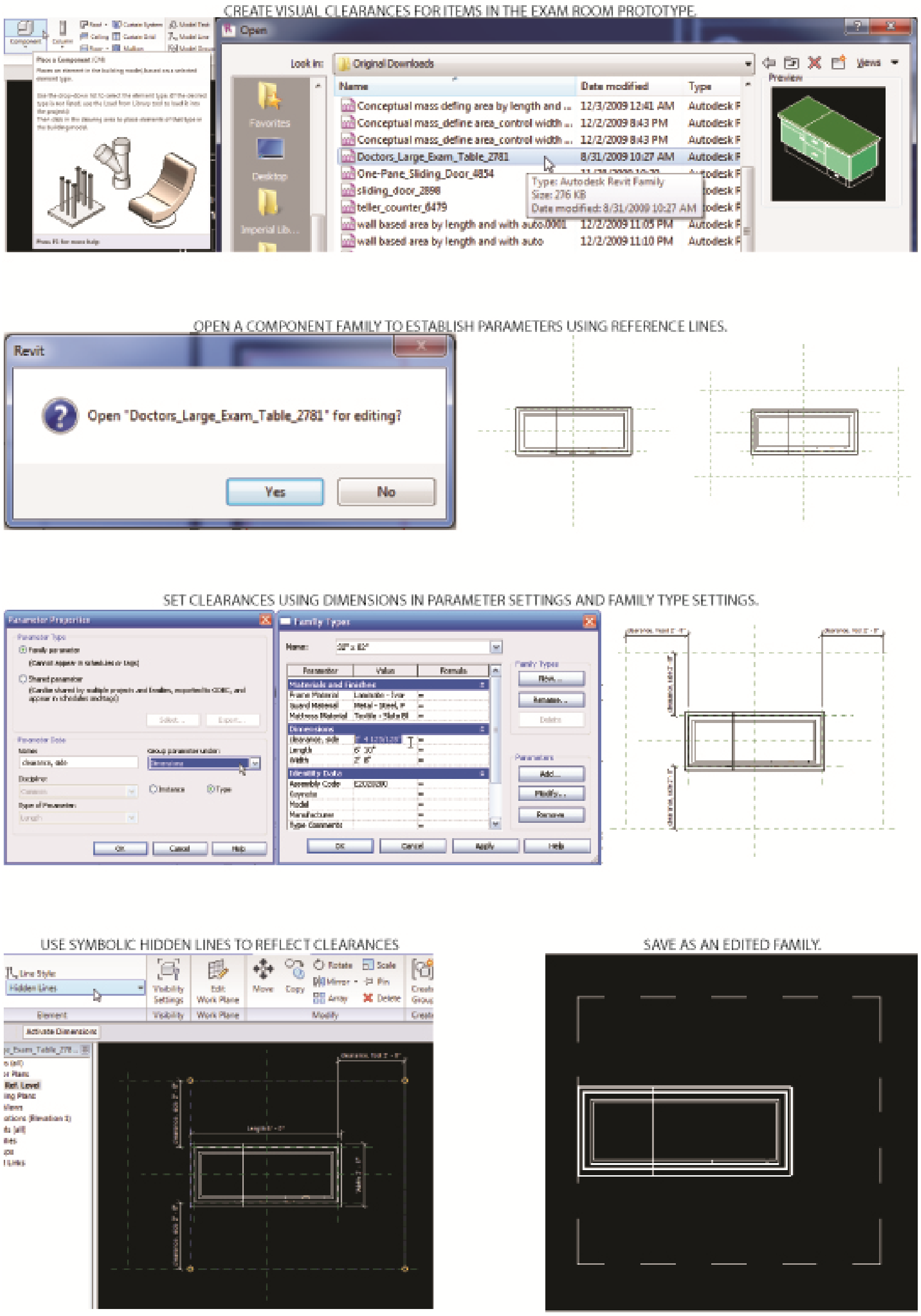


Figure 41 *Creating parameters to reflect necessary clearances for the exam room prototype.*

As prototypes develop over time or components becoming altered due to changes in guidelines and so forth, new iterations of the prototypes can be saved as edited file. A simple file management action is duplicating this component within the current project and changing the file by adding "e1" to the end of the file name keeps the original file and allows for the component to be altered according to a project's specific needs. Keeping the original name gives the ability to reference back to the original download. Adding "e1" is similar to saying "edit 1" and with every new change the end of the file name should be saved according to the number of alterations. (e2, e3, e4….) This project will contain the project components under its own file location (My Healthcare Design Library > Examination Room > COMPONENTS > Doctors_Large_Exam_Table_2781e1)

In the same way an exam table is loaded into this project, families include countertops, cabinetry and sinks which are also loaded into the project. This is one example of apply information relative to healthcare design and putting it into a modeling system. There are many other pieces of information which need to be implemented into a modeling system. The basis of this research rests on the idea that building information modeling can house the imperative information relative to healthcare design.

For the start of this prototype another action is setting schedule parameters. While some parameters are arranged to depict accurate visuals of spatial needs, setting parameters within a schedule support monitoring specific data particular to healthcare needs. As one example, the schedule conveys data information concerning the room area (Figure 42). In a project a room is defined by room bounding objects such as wells. By selecting the room tool and the space which is desired to be defined, Revit can then recognize the room space. Within the room tool an option to calculate Areas and Volumes is available. By creating a new room schedule options for arranging the information can be done using fields, filters, sorting/grouping options, formatting, and/or appearance. By selecting the option to create a Calculated Value Naming it "Room Floor Area SF" a formula can be defined for calculating "Room: Volume / Room: Unbounded Height" will generate the result of the Room Floor Area.

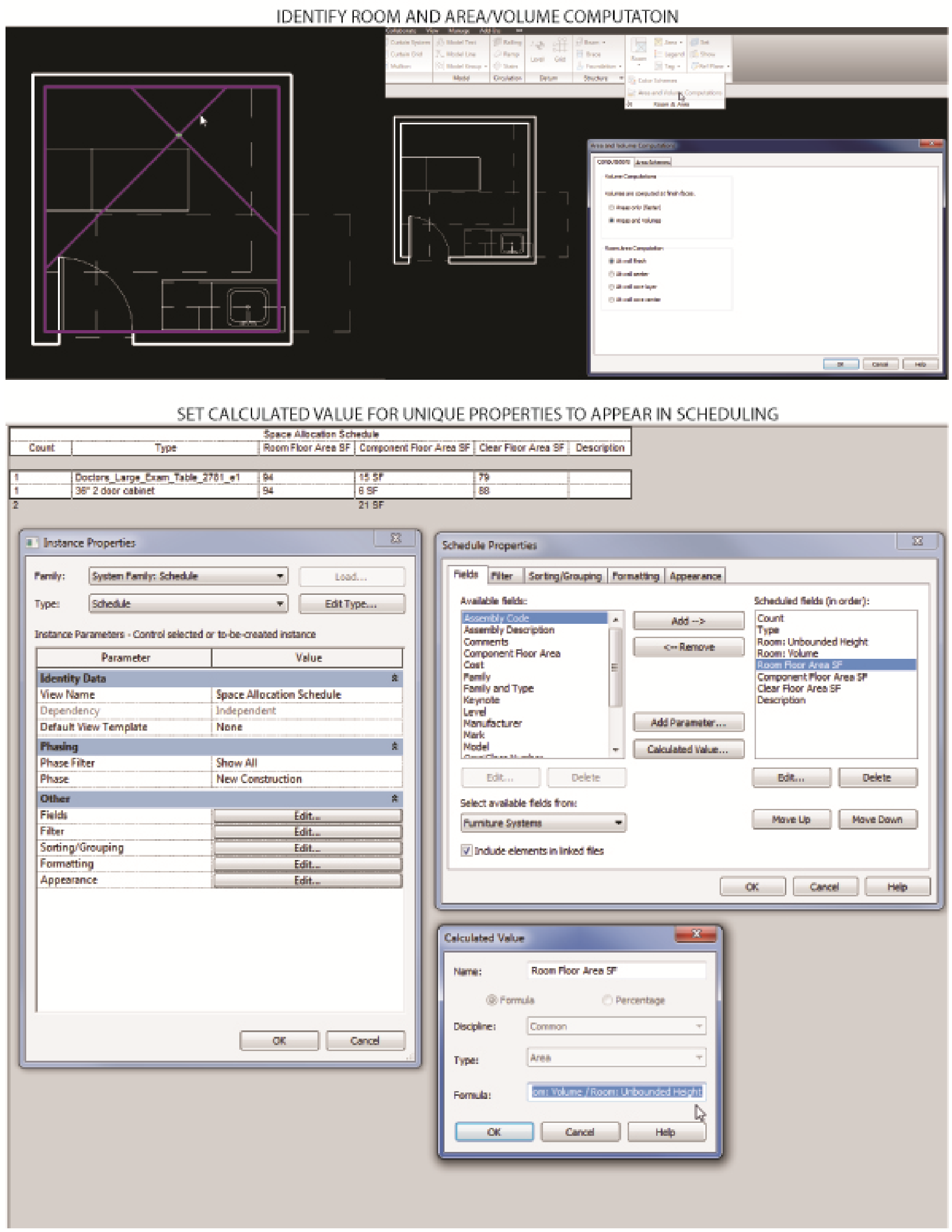


Figure 42 ***Unique parameters set in healthcare prototypes are supported by calculated data conveyed in schedules.***

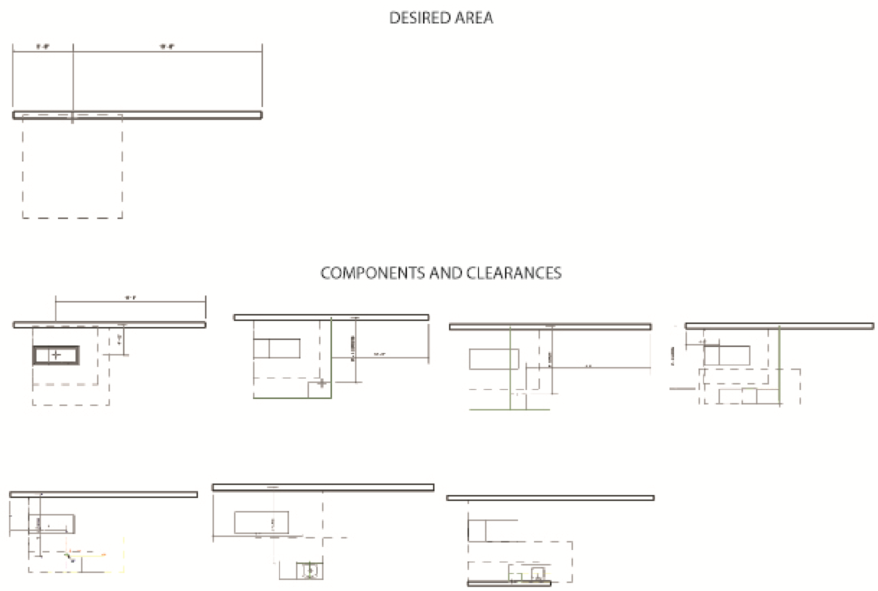
While the Desired Area parameter previously mentioned is created and can visually reflect area requirements in the model, the data of actual calculated square feet is communicated directly into the schedule. Using formulas to establish calculated values becomes added accountability on the prototype. Reviewing the data in schedules is an accurate check on the design of the prototype model in reference to the guidelines laid out for different healthcare spaces.

With the understanding of these actions 1) setting parameters for a Desired Area, 2) obtaining appropriate components, 3) setting parameters for clearances and 4) setting schedule parameters the following two sections exemplify this setup for an exam room prototype and a pharmacy prototype according to the recommended guidelines.

6.2.1.1. Rules – General Examination Room Prototype

Prototyping for healthcare spaces using the basic parameter setup for Desired Area, Clearances and Scheduling is demonstrated in the development of a General Examination Room Prototype. With the parameters and family components set up they are simply loaded into the project. Loading in the necessary components can be done in any order. However, a suggested order for prototyping healthcare spaces illustrated in Figure 43 is the Desired Area which communicates minimum area recommended by the guidelines, then the components with clearances along with drawing walls. After placing all these parts that make up an exam room, schedules can be included for managing the spatial information such as the Room Area SF mentioned earlier and/or other items involved in the project defined by the schedule properties. This is just one example of applying the customized rules setup for an exam room prototype.

In addition to this, other derivatives of a general examination room can be developed by making alterations to an original prototype and saving the project file in the name of the new space. Figure 44 shows the original general examination room prototype reconfigured to develop an observation room prototype. This prototype of an exam room is executed with reference to guidelines for the design and construction of healthcare facilities. Using the General Examination Room prototype variations can be made and saved as new files thus providing base prototypes for different types of exam rooms. Guidelines convey exams rooms aside from the General Examination room, which are Special Purpose Examination Room, Treatment Room and Observation Room. From the initial General Examination Room prototype, new prototypes can be developed based on guidelines for these other types of exam rooms without returning to *tabula rasa*. These other types still maintain strong similarities to each other. Therefore prototypes build and expand from each other. This is the beginning of creating and investigating BIM prototypes for healthcare design.



COMPONENTS AND CLEARANCES

Room Schedule					
Number	Name	Area	Unbounded	Volume	Comments
1	Room	94 SF	10' - 0"	940.50 CF	

Space Allocation Schedule					
Count	Type	Room Floor Area SF	Component Floor Area SF	Clear Floor Area SF	Description
1	Doctors_Large_Exam_Table_2781_e1	94	15 SF	79	
1	36" 2 door cabinet	94	6 SF	88	
2			21 SF		

EXAMINATION ROOM PROTOTYPE

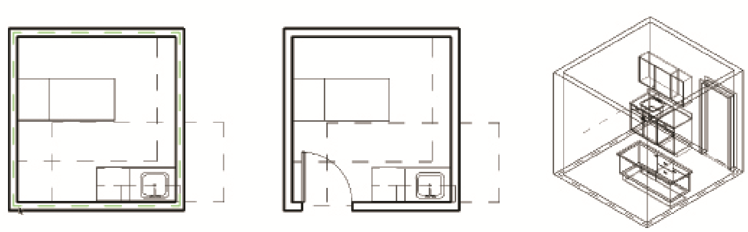


Figure 43 ***Parameters inspired by healthcare guidelines used for a General Examination Room Prototype.***

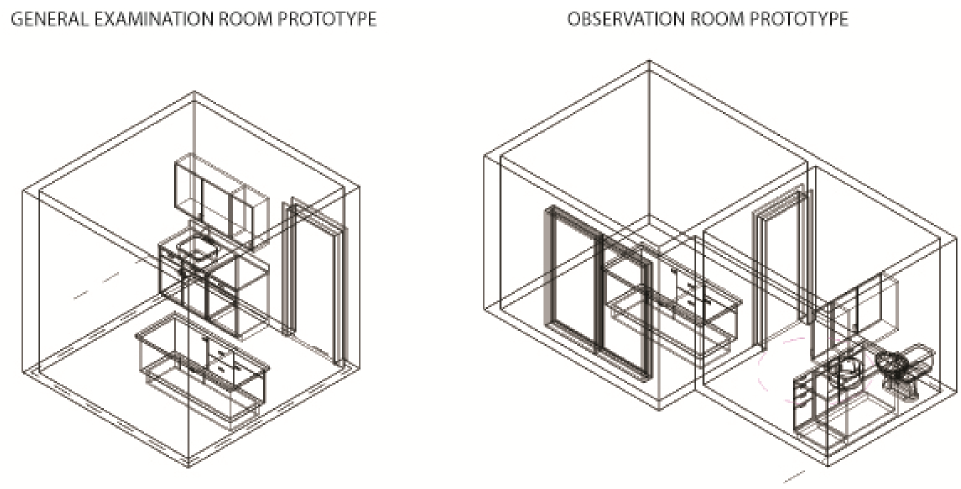


Figure 44 ***Observation Room prototype is developed from General Examination Room Prototype.***

6.2.1.2. Rules - Pharmacy Prototype

In the case of setting up guidelines for a pharmacy a template (Figure 45) was available in a 2D AutoCAD format. Using the AutoCAD file as a reference and underlay provided some level of collected information. Rather than setting parameters inspired by design guidelines for healthcare facilities, such as in the example of the General Examination Room prototype, this prototype begins its setup based on credible digital template information provided by the client. The value of using the 2D template is mostly that it communicates given dimensions. The prototype developed using a BIM approach has a basis from the template.

Researching information from the 2D template is made reference similarly to researching information in the guidelines for healthcare facility. The one larger difference is having dimensional compatibility between digital files, but the data in the 2D template is not coordinated automatically into BIM tools, such as Revit.

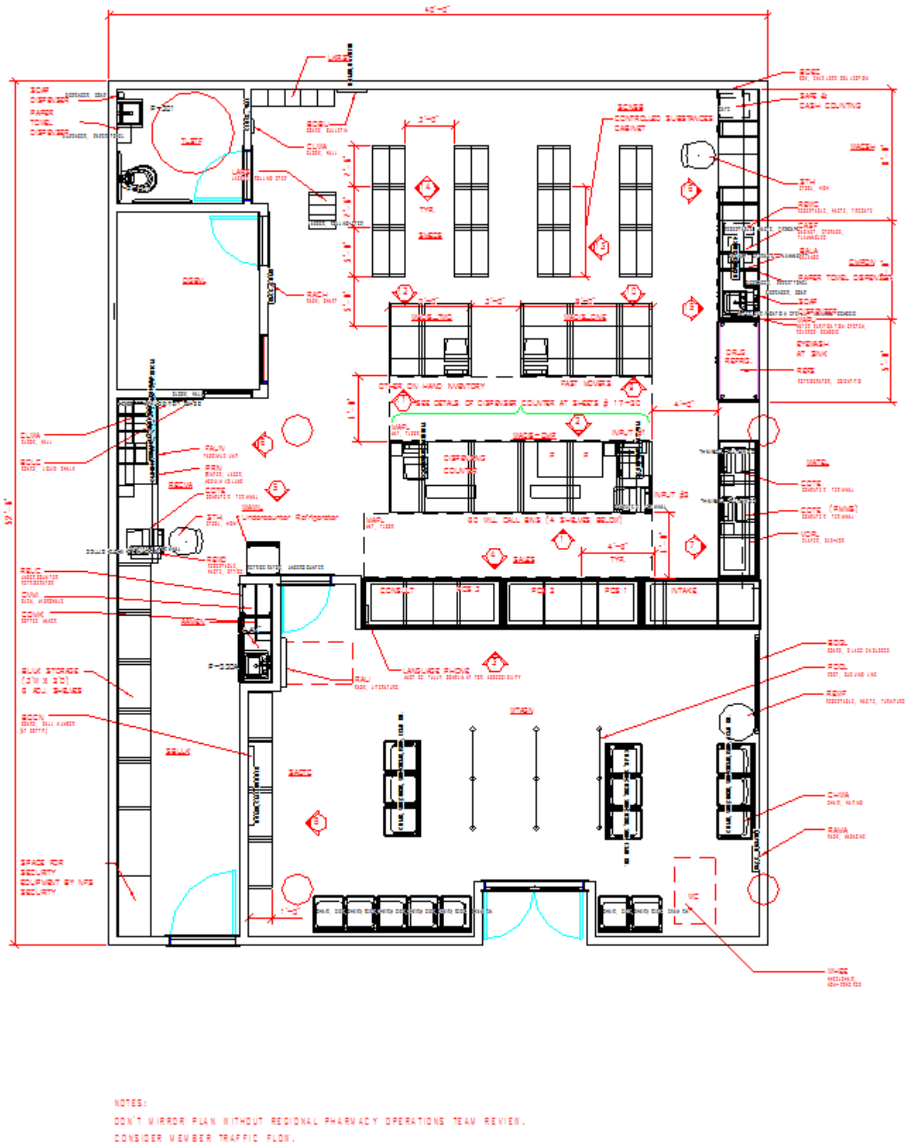


Figure 45 ***Pharmacy prototype is based initially on the dimensions of the 2D template.***

Referring to the CAD template, some rules and components are identified. This is a manual transfer of information (Figure 46); similar to referencing information in a book, except in this case it is in a different computer application tool. Once components are identified they can be gathered, using the same approach as mentioned in developing the exam room prototype, to produce a pharmacy prototype.

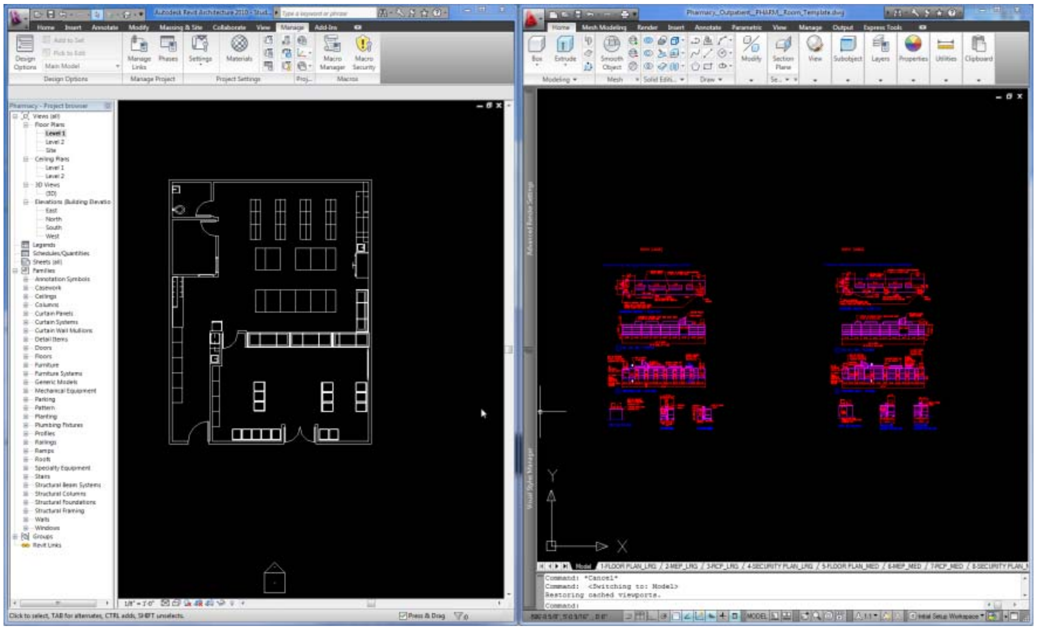


Figure 46 *Typically manual referencing of information between 2D template into Revit.*

While several components are available to include in the prototype, a pharmacy requires some very specific pieces of equipment. Some components have been produces and contributed toward open source sites such as a ducted laminar flow fume cupboard (Figure 47), used in some pharmacies. This is just one example.

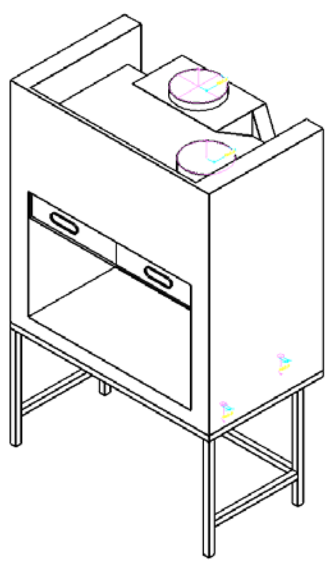


Figure 47 *Pharmacy equipment – Ducted laminar flow fume cupboard component.*

Using the available components and the 2D CAD template for limited dimensioning reference a pharmacy prototype is developed. While the need for pharmacy spaces is not repetitive in the layout of a healthcare facility the prototype serves as a basis for different design projects. The pharmacy prototype (Figure 48) contains the fundamental needs for a functioning pharmacy design and reconfigurations can be made depending the unique needs and details of individual design projects.

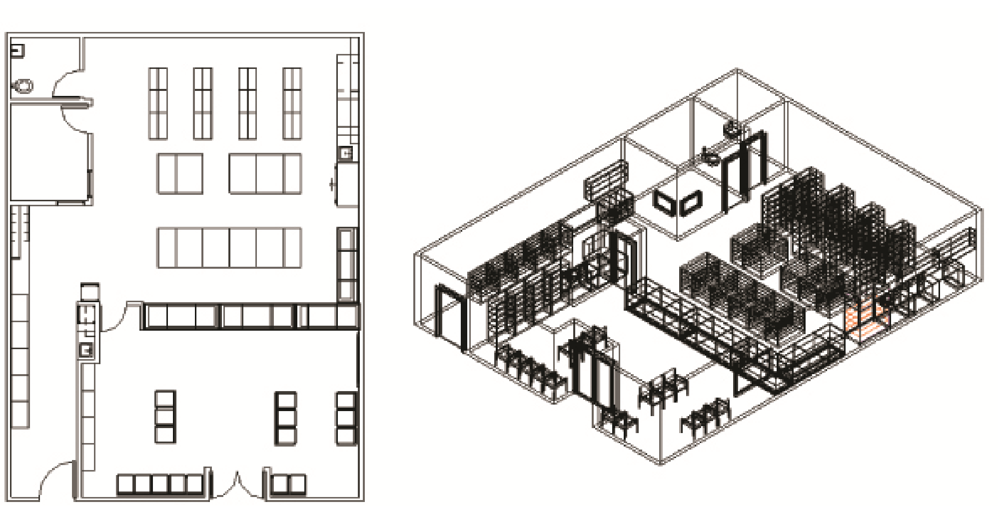


Figure 48 ***Pharmacy prototype.***

Acquiring components for specialized professions still depends on open source availability. Sometimes components are provided by a manufacturer, the Sweets Catalog has been a common source for obtaining particular product needs. Lately the Sweets BIM collection has been growing. However, registration and other account type requirements are necessary for access to their growing library of products. If components for pharmaceutical equipment or other healthcare spaces are unavailable basic components can be self-produced representing approximated detailing for the sake of the project or can be represented by dimensioned forms mimicking the required component. Importantly, BIM is about having informed modeling so the quality of information is critical to the worth of the BIM model outcomes. BIM modeling is dependent on the available information. In time as more information is received, BIM prototypes are flexible to exchange or received new information.

6.2.2. Integration – utilizing BIM prototypes into design projects

A prototype carries foundational information and is setup according to the appropriate rules and guidelines for the specific healthcare space. Because of the coordinated information that the prototype withholds the key to integrating the prototype into a healthcare design project (Figure 49) is have all the information transfer without losing any information or losing the proper coordination of information. For the case study, a portion of the project is renovation of an existing structure. After demolition of some existing structure, is redesigned requiring a couple of general examination rooms in a specific location. During the BIM process of design, integrating the general examination room prototype accomplishes design needs and maintains the original prototype information. Rather than design traditionally and controlling each component piece by piece and then checking each detail to make certain that all aspects are abiding by healthcare guidelines. The prototype already includes all the calculations.

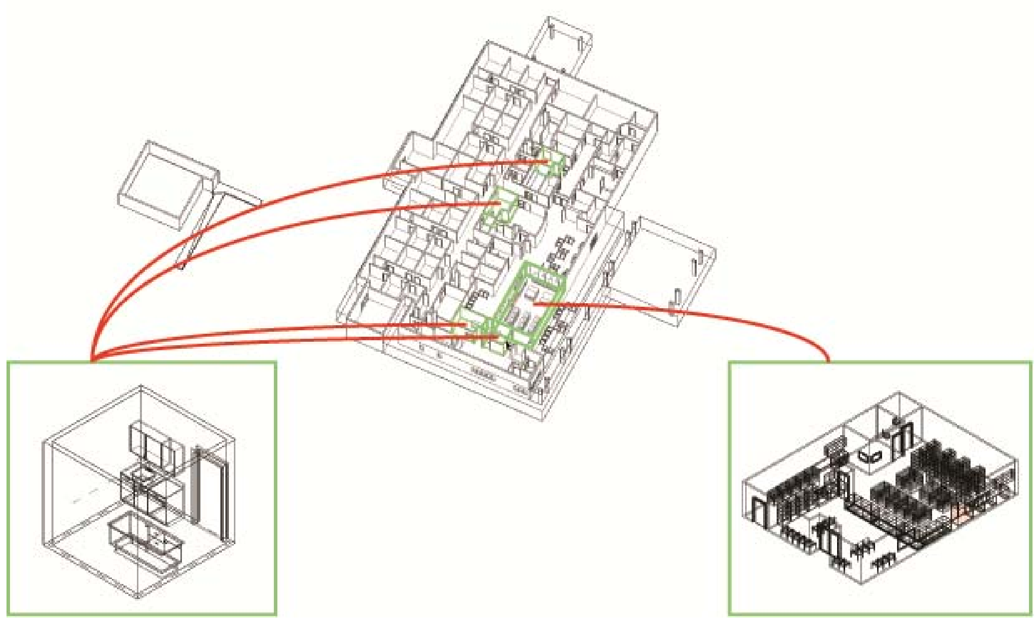


Figure 49 ***Integrating General Examination room prototype and Pharmacy prototype into a design project.***

6.2.2.1. Integration – General Examination Room Prototype

Within Revit the option to link one Revit project into another is available but for simply beginning the process of integrating a basic prototype. The common method of copying and pasting works as well. For this exam room prototype, regardless of what option chosen to integrate, once it is brought into the healthcare design project, creating it as a group and naming by its prototype name within the project will support managing the overall project throughout the duration of the BIM process. As long as the prototype exists as a group, the components within will be maintained. Some alerts occur (Figure 50) when placing the prototype within the renovation project. Walls representing decided space allocation for the examination rooms exist in the design project. When integrating the prototype, an alert is recognized. There are conflicts in the walls, in order to maintain the integrity of the prototype, opening up the group, cutting the walls so the prototype wall is the host maintains certain components with a wall dependent relationship. In this case, wall dependent components for the exam room are the upper cabinets and electrical outlets. Making this adjustment in the group itself, maintains the prototype and allows for it to be placed amicably into the renovation design project.

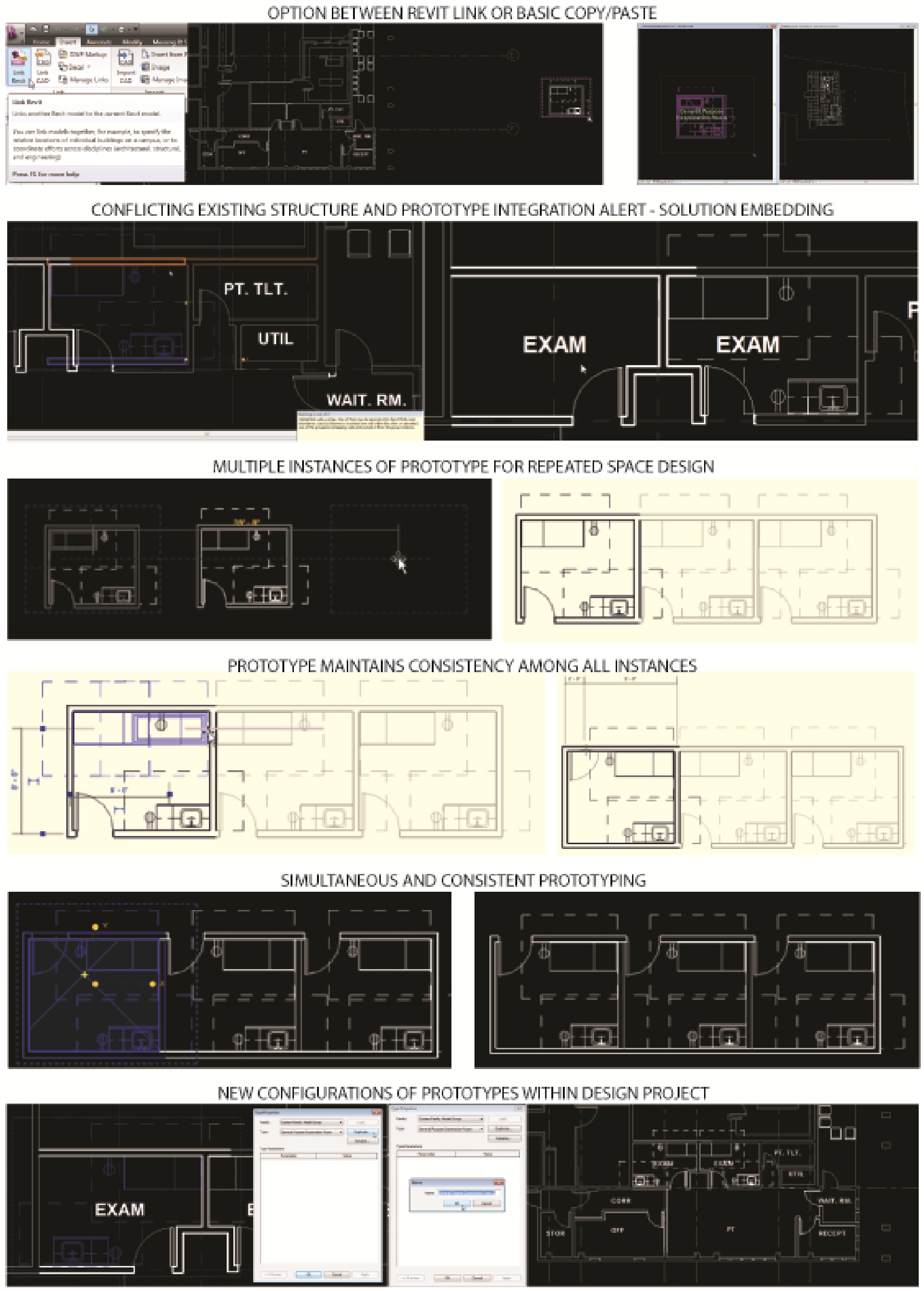


Figure 50 ***Integrating and using prototypes in a design project.***

In this case, the decision was to have two exam rooms next to each other. While this is a renovation project, some walls must be maintained. Creating a second instance of the general examination room group that was initially created up on integrating the prototype is used for executing the second examination room space. In the case of other projects, perhaps a new construction project, an advantage behind this is maintaining prototypes as groups allows the ability to make changes and maintain coordination to all rooms placed in a design. Because of space constraints in the renovation project an exact replica of the exam room cannot be used. So when placing the instance and creating it as a new group will allow for unique adjustments without having influence on the earlier integrated prototypes. The groups define the relationship of any new configurations to the prototypes.

These are the basic actions involved with integrating a prototype for a general examination room into the case study of a renovation for a primary healthcare project.

6.2.2.2. Integration – Pharmacy prototype

The same way the exam room prototype was integrated into the project, so is the pharmacy prototype (Figure 51). Prior to including the pharmacy prototype was designed a space for a waiting area. Since the pharmacy prototype contains a given waiting area, it is not needed for the project. When the pharmacy prototype is brought into the project and made into a group within the project. Then actions toward reconfiguring the space can occur. Removing the waiting area from the prototype, the pharmacy is now configured to the needs and space constraints of the existing structure as shown in Figure 52.

Figure 51 ***Integrating a Pharmacy prototype into a design project.***

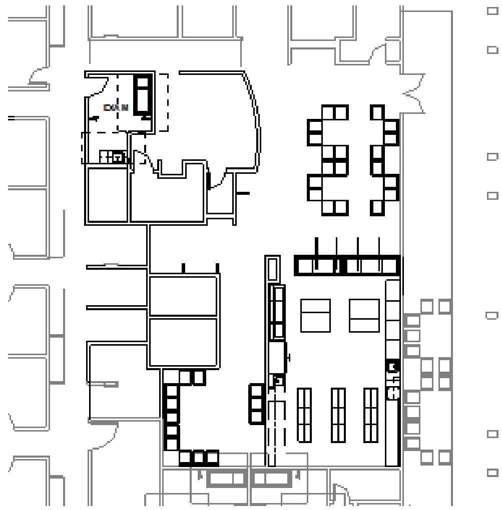


Figure 52 *Integrated Pharmacy prototype.*

6.3 BASELINE MODEL: CONTINUITY THROUGH BIM

The purpose resting at the root of BIM is the consistently consolidated exchange of information which makes available the ability to make simultaneous and coordinated actions to a design project. Utilizing the BIM process is not contained in one design project but can be implemented throughout the duration of a building's lifecycle. Buildings undergo change with time and BIM supports these changes. Applying baseline modeling provides the foundation information to lead into future changes more effectively. In the case of healthcare facilities, aside from common changes to a building, the expansion of the healthcare profession requires changes and improvement in the buildings facilities as well. Observing a couple of approaches in the BIM process of design, post-construction actions by applying baseline modeling makes available information regarding the healthcare facility environment for research and the advancement of healthcare design as a whole. Two examples of applying baseline modeling are 1) sharing of the BIM model designed in Revit through other cooperative applications and 2) using information databases having a coordinated relationship to the model.

6.3.1. Continuity and sharing of BIM model

After a healthcare design project is entirely complete and made fully active, it is expected that in the future post-construction inquiries are made with relation to the healing environment or anticipated design alterations. Applying a baseline model provides detailed information of latest building design attributes. The baseline model offers data about the environment which healthcare professionals can investigate with respect to the healing environment. The baseline model also offers a solid foundation of information which can be utilized for future building designs or renovations. Applying baseline models for the sharing of prototypes with healthcare professionals contribute data which can be used to investigate the healing environment for specific areas of a healthcare facility. Figure 53 illustrates that designers can pass on a baseline model to the client and control the level of information they are willing to make available without the client needing to use a complicated architectural design application. The baseline model is exported as a specific file type or saved through an add on in the Revit program. This allows for the BIM tools to communicate the BIM model to one another. Among other BIM tools the model can offer can undergo other levels of analysis, or observation depending on the purpose of inquiry.

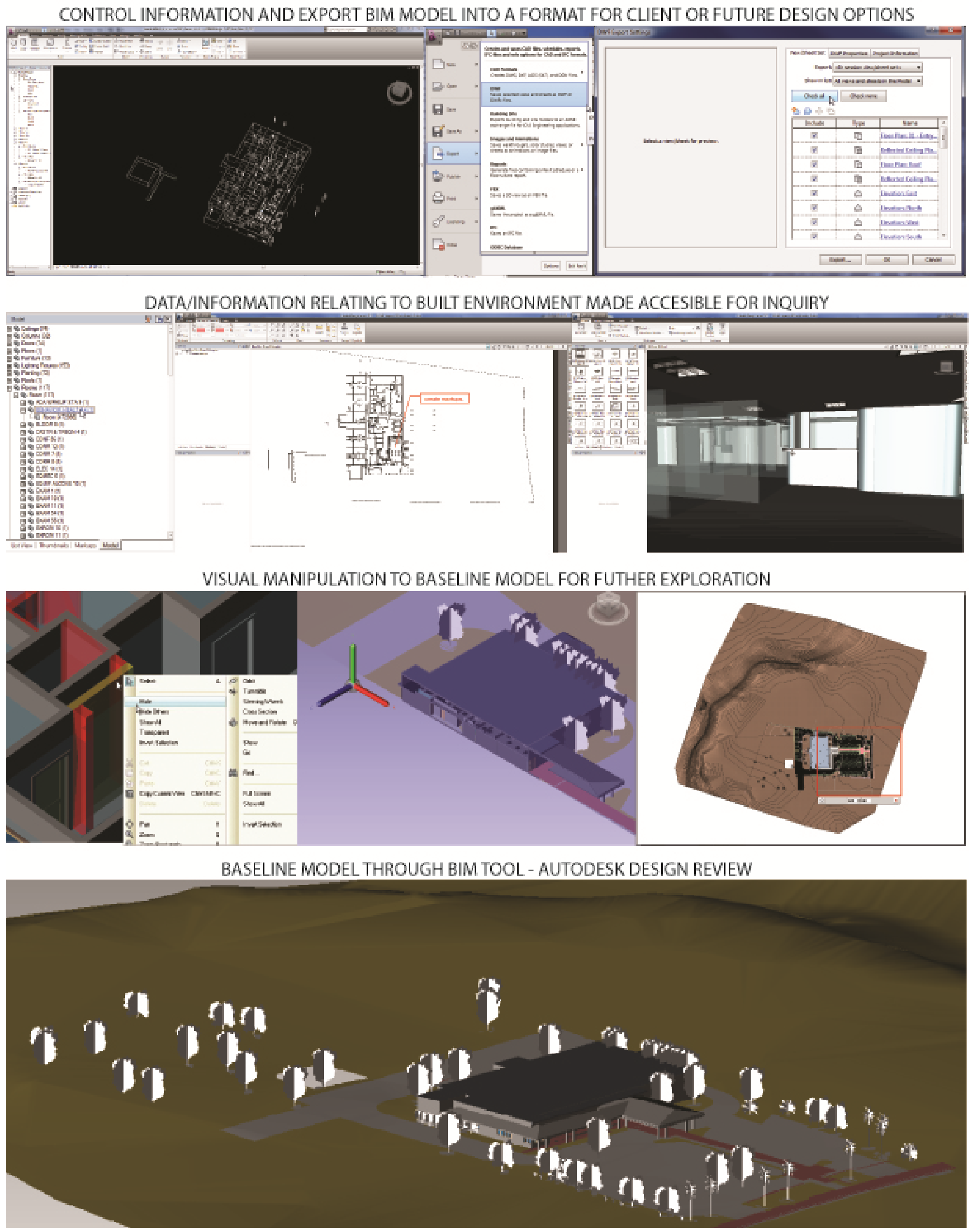


Figure 53 ***Example of applying baseline modeling by exporting BIM model into other BIM application tools.***

Using Revit for the case study, a compatible application for producing some levels of a baseline model is using Autodesk Design Review. Within Revit, an option for exporting different file types is what allows for a controlled sharing of information. By exporting the design project to a DWFx file it produces the model in a format which does not allow for direct design alterations, but does allow the ability to inquire into the details of the design project. This format is analogous to printing to a PDF file. There option to alter the design is not available but the details for reviewing, marking up, commenting, measuring is offered for the sake of inquiry. This file format is more strictly a visual exploration of a baseline model.

On a smaller scale, baseline models of BIM prototypes contribute specific information about the unique spaces in a healthcare facility. For example Figure 54 shows the start of a BIM prototype for a patient room which is one area that is researched for EBD application. For future studies a baseline model of this space can be shared with researchers so they can apply the data as contributing results toward a specific research topic. Apply the use of a baseline model exported from BIM prototypes supports healthcare designers and healthcare professionals the solid data for investigating the healing environment. Without formal publication, the information cannot be considered official case studies, however applying baseline modeling does supply solid data on which investigations for formal case studies can build upon.

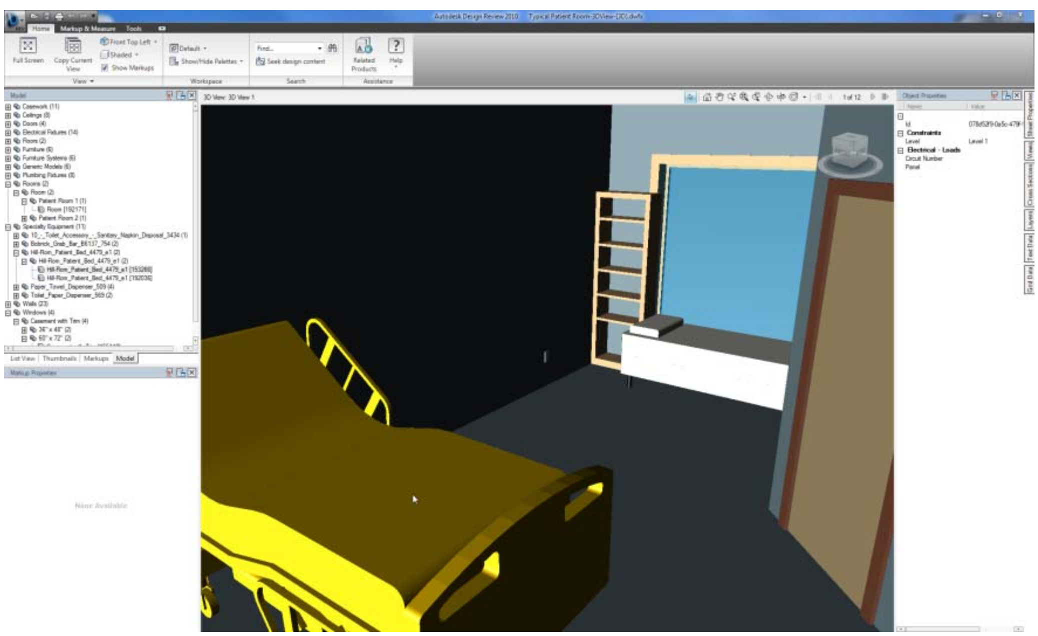


Figure 54 ***Baseline model of a BIM prototype for a typical patient room.***

6.3.2. Continuity and sharing of BIM data information

Another example of baseline modeling is using the BIM model and establishing a direct and continuous transfer of information to a database system. In this example situation (Figure 55), changes in the model and/or changes in the database system has simultaneous interchange and affect on each other.

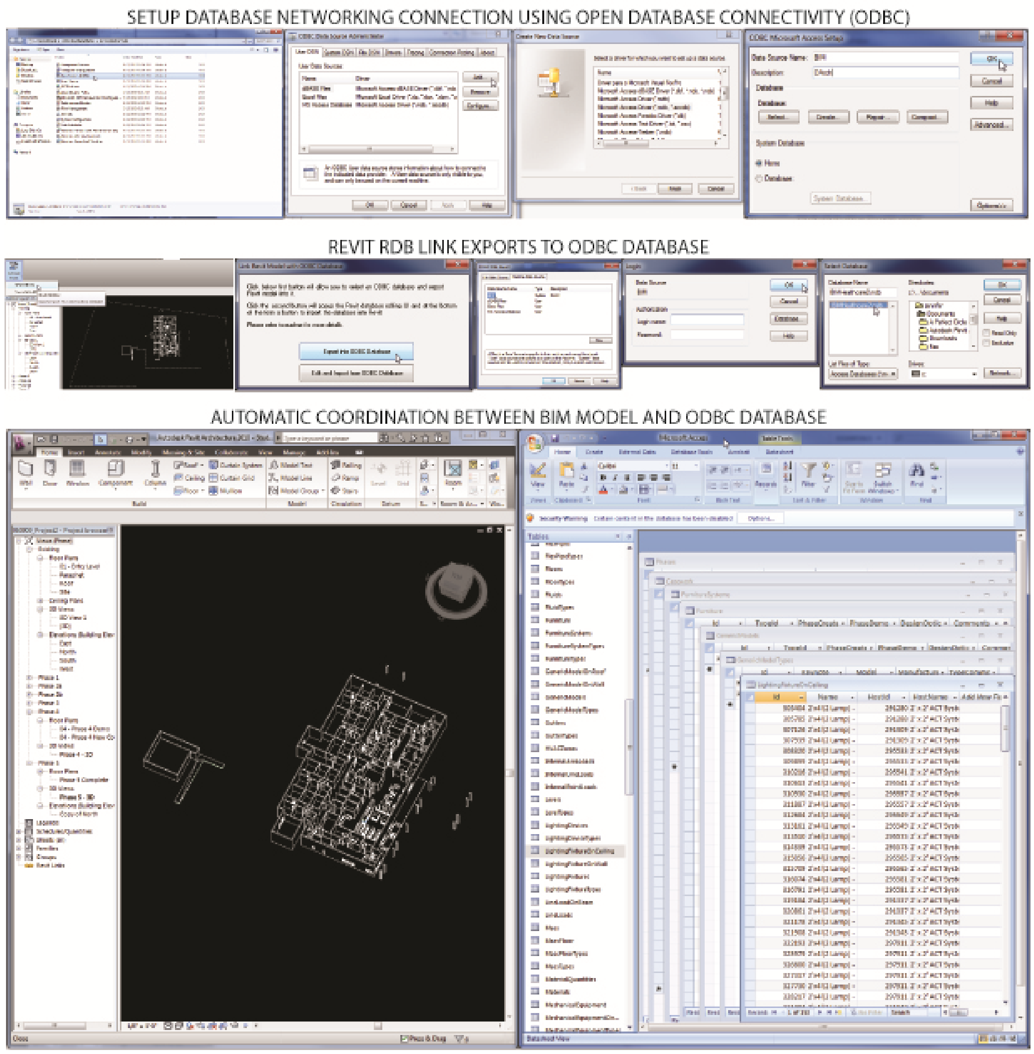


Figure 55 ***Baseline model of a BIM prototype for a typical patient room.***

Networking a database system involves setting up a network through administrative tools in the operating system of a computer. Using Data Sources for Open Database Connectivity (ODBC) a data source is created for transferring the

Revit project data into a collection using spreadsheet tables. From the other end of the connection within the Revit application a plug-in for external tools is to be downloaded. The plug-in is Revit RDB link. With this link communication is established between the project model and the spreadsheet for managing data information.

The relationship between the BIM model and the database system makes it feasible to make alterations to features in the model and then the change automatically is coordinated in the database. This also works in reverse; if you change items in the database system it will make changes to the model.

This example allows accessibility to the details of the project. The availability of information this baseline model offers enables future design decisions to be based on the awareness of previous design information. It also enables healthcare professionals to be more aware about detailed information regarding the healthcare environment.

6.4 SUMMARY

In this section, three strategies, phasing, prototyping and application of baseline model, are pursued for the BIM process implemented into a case study project for a healthcare facility. Along the lines of phasing, the ability to setup the phases according to priorities in healthcare design allows building professionals and healthcare professionals to look ahead at the actions and activities necessary to monitor during the design and construction process. Phasing allows for increased awareness of safety and supports preventative managerial actions for monitoring the priority issues of a protective environment of the healthcare facility. Prototyping establishes a consistent and ongoing means of scenario testing. Using prototypes for scenario testing requires setting up appropriate rules and parameters in order to make specific evaluations base on detailed alterations. Prototypes are also a basis for specialized healthcare spaces which can be integrated into healthcare design projects and can be further developed as an isolated part of the whole design. Applying the use of a baseline model provides a sound foundation of information to be shared for future design projects or redesign of the latest existing structure. The data which baseline models carry is very useful for future developments in healthcare design for both healthcare designers and as a contributor to the advancement of the healthcare profession.

7. OUTCOMES

BIM model communicates between various BIM tools, for this research the primary and initial BIM tool used is Revit. Communication of data is coordinated and is shown in a few images of compatible BIM tools in the processing of understanding the relationship of information between various methods of analysis.

In Figure 56 the use of Revit to initialize a BIM model reveals various views in scheduling, 3D section views, plans and walkthroughs. The infrastructure of the BIM modeling process for design begins with the information input into Revit. The detailed pieces of information, from GIS generated topography to voltage information for lighting systems (Figure 57) are put into the Revit model and communicate out to various other BIM tools. Transferring detailed information from Revit also includes the groups made from integrated prototypes and the customized scheduling information (Figure 58). This is the chosen BIM tool for this research to begin with establishing the design. In Revit all views can be organized with the phasing strategy and transfer into other BIM tool applications.

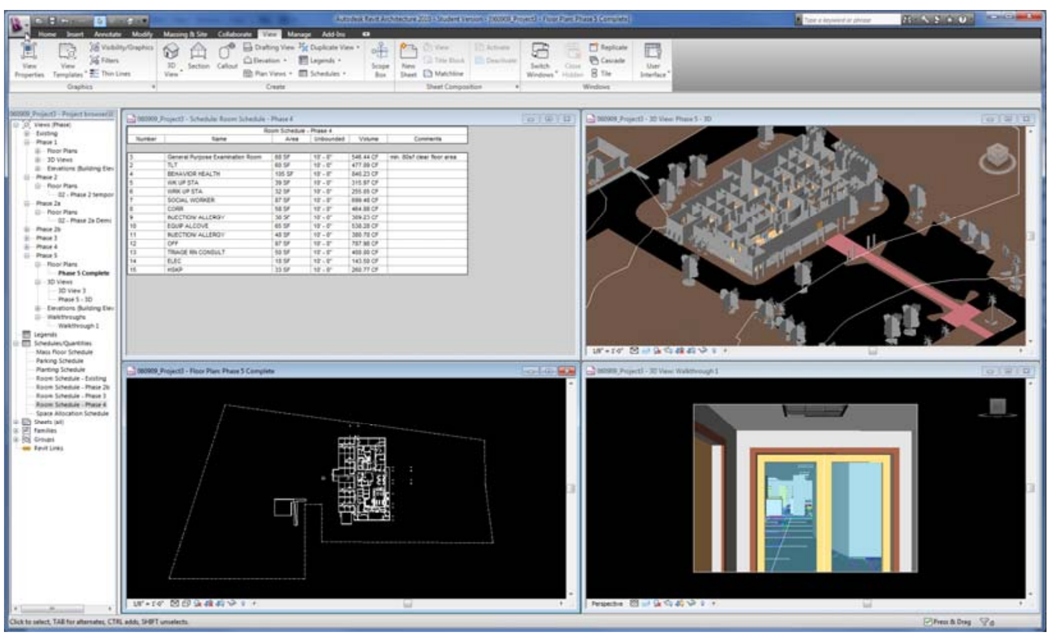


Figure 56 *BIM modeling in Revit.*

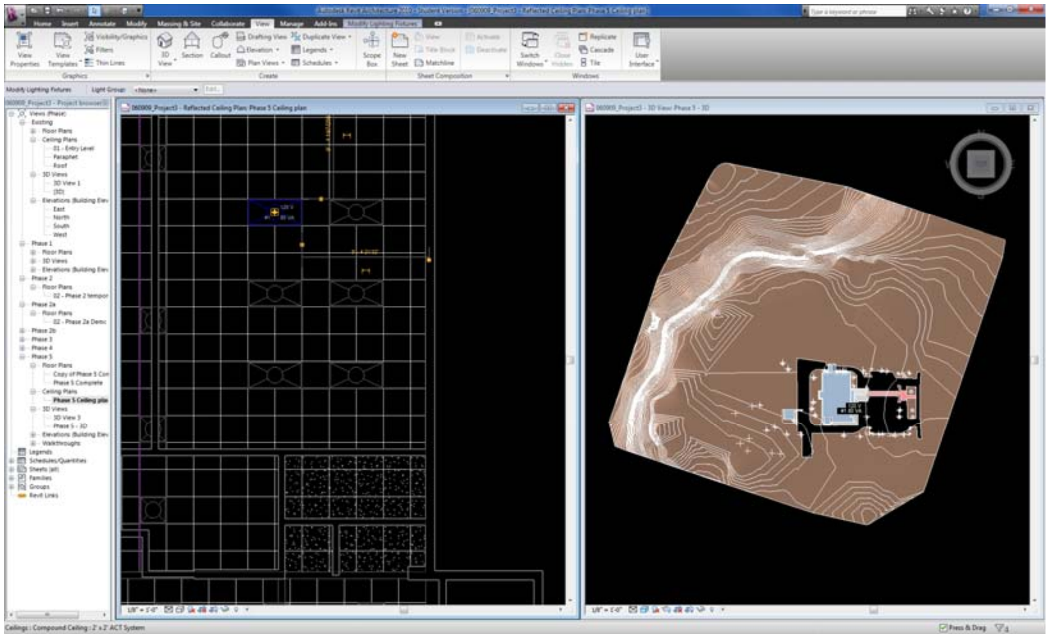


Figure 57 *BIM modeling in Revit of lighting details and GIS imported topographic form.*

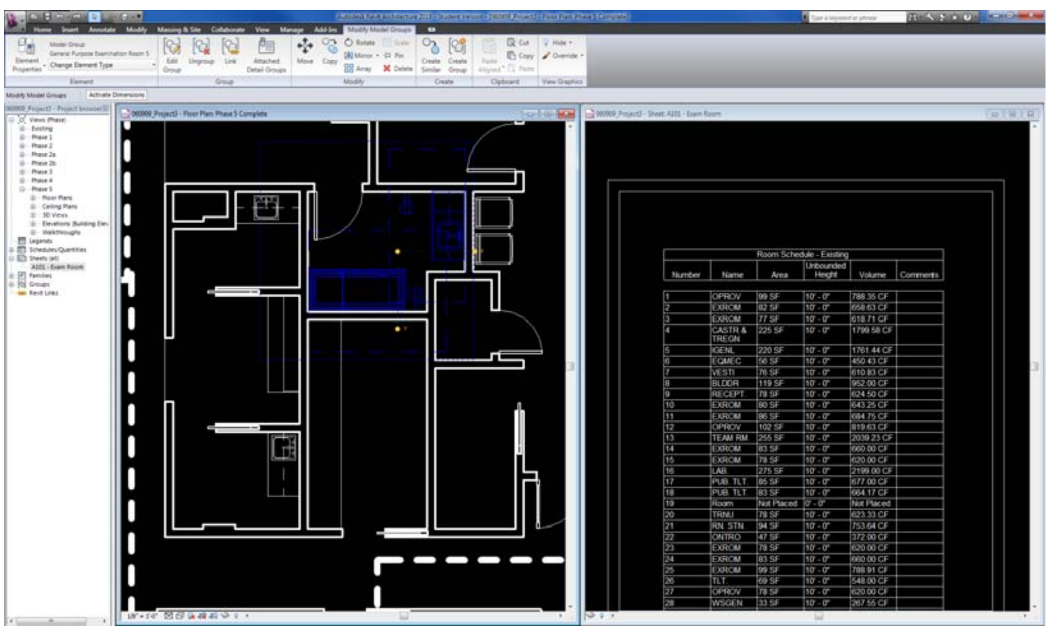


Figure 58 *BIM modeling in Revit of prototype grouped and scheduling on a sheet.*

Using the original BIM model devised in Revit, the transfer of data and model is shared in the application Navisworks. Navisworks is not an application for creating a BIM model rather in this BIM tool application is where a relationship between all the information set up in Revit is networked with a schedule created in another outside information management system called MS Project. However Navisworks is the information management system which can coordinate the scheduling with the BIM model (Figure 59). The different details involved in scheduling can be viewed using this tool as well (Figure 60). This affirms the correct items are connected with the appropriate scheduling information.

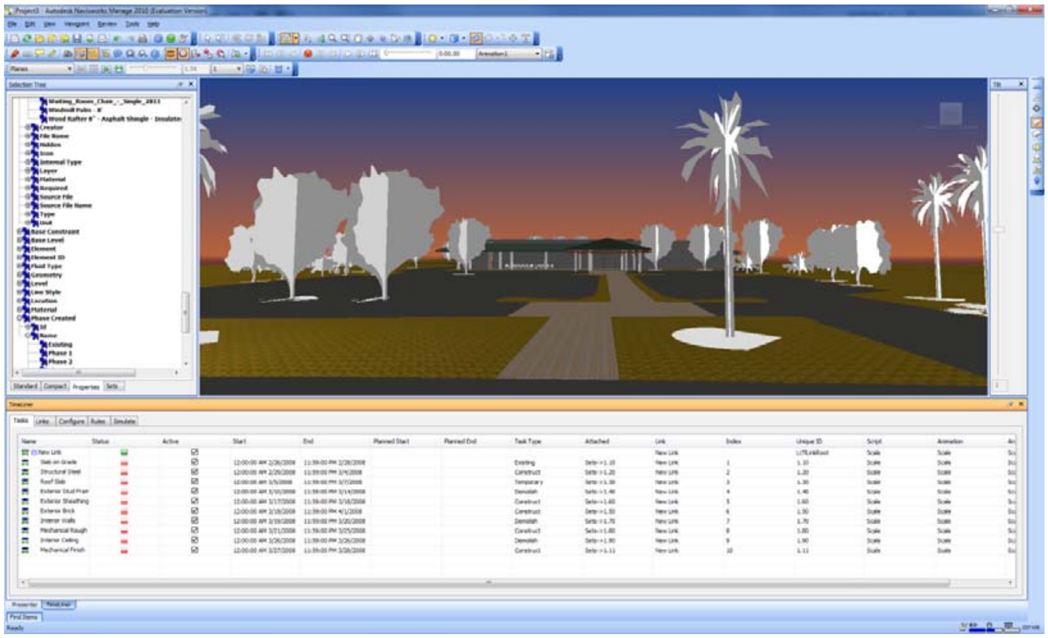


Figure 59 ***BIM model coordinated from Revit to Navisworks information management system***

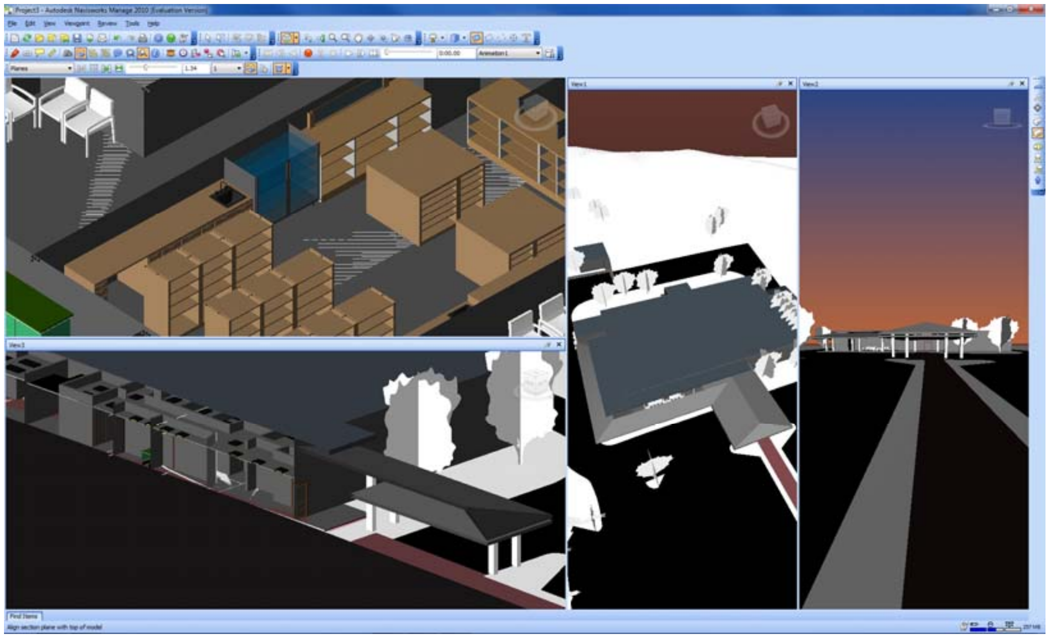


Figure 60 ***Detailed items of BIM identified with detailed coordinated scheduling.***

Another BIM tool application which information from the original BIM model transfers into is Design Review. A casual way of describing the viewing features of this BIM tool application is like viewing a .pdf file. The BIM model brought into Design Review allows users to make minimal automatic coordination with other outside tools. This simply holds information for viewing and making notes without tampering the actual BIM model. Figure 61 is an example of a view with options to navigate around the model. Part of using Design Review is also for the ability to select different objects to make inquiries about the details (Figure 62). Information included in the original BIM model can be shared for review and notes can be directly added in with association to the reviewed items. While the markup is created primarily for the building industry (Figure 63), it is still usable for others such as healthcare professionals to use when reviewing a design for a healing environment.

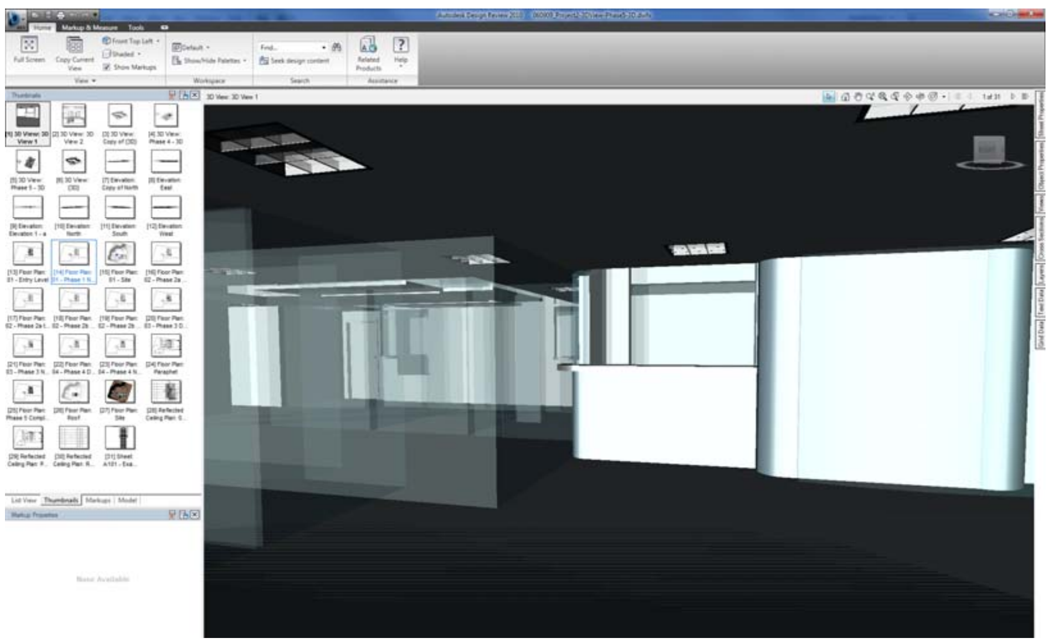


Figure 61 ***BIM model coordinated from Revit to Autodesk Design Review information sharing system.***

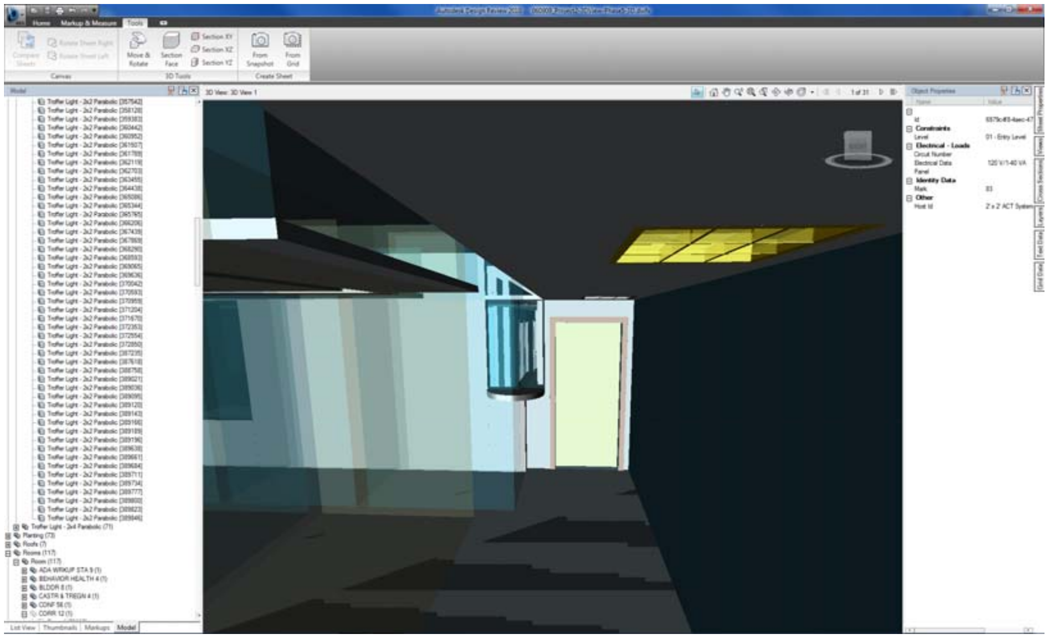


Figure 62 ***BIM model in Design Review – detailed objects inquiry***

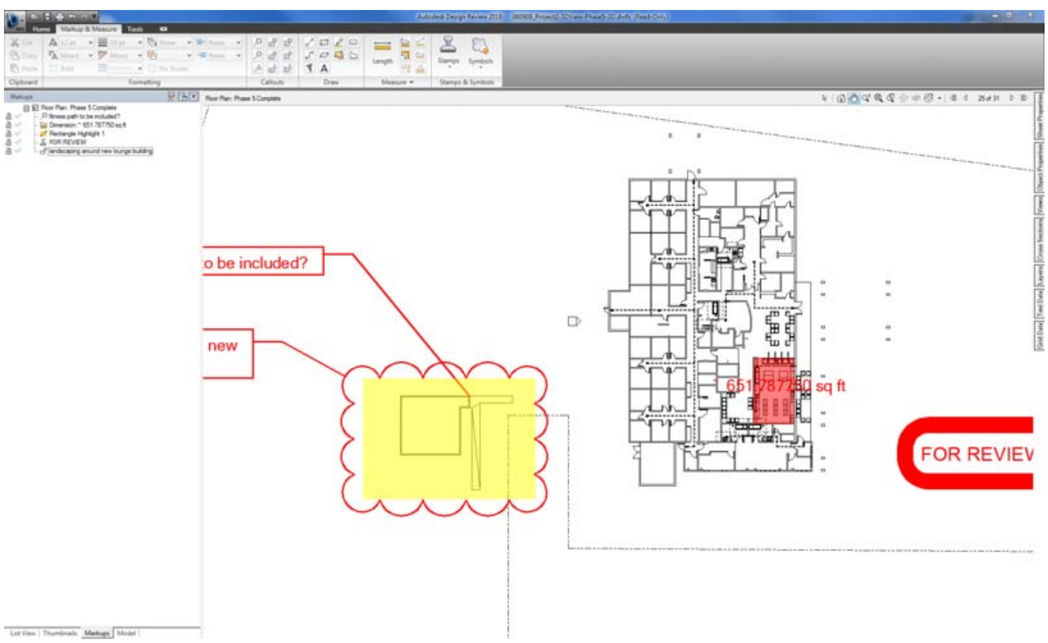


Figure 63 ***BIM model within Design Review marked-up for review.***

MS Access is an information database system. By using the Revit RDB link a continuous access of information can be communicating between the original Revit model and MS Access information database through an ODBC connection. This sharing of information contrasts Design Review. Design Review does not allow for a transfers to and from each BIM tool application whereas with through ODBC MS Access and Revit can affect each other. The visual objects seen in Revit are not visible in MS Access however the information connected to the objects is in MS Access. Changes to the objects or changes to the database information will alter each other directly. Different types of information are organized in appropriate categories which are consistent with the organizational setup in Revit as well. Figure 64 shows the database information related to the Revit model.

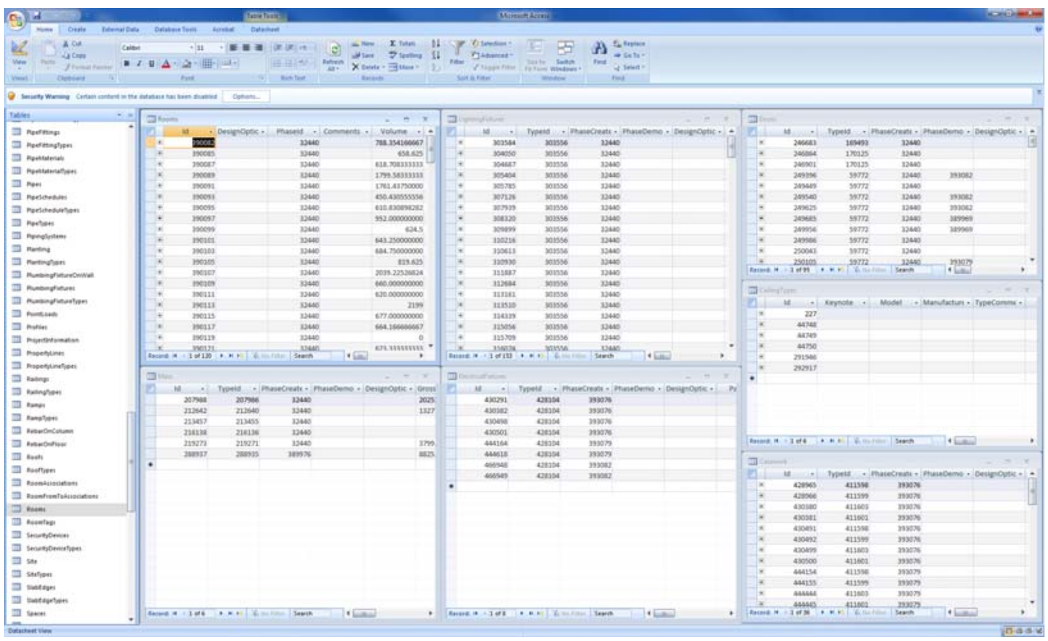


Figure 64 ***BIM model coordinated from Revit to MS Access database system.***

8. DISCUSSION

In this research, the needs for BIM in healthcare were identified by the fundamental nature of the healthcare profession in the scope of the provided diagnostic/treatment involved in their service, the functional space necessary to house the services and the tools/equipment which healthcare professionals are dependent on to provide the appropriate care. All of these parts in the nature of healthcare are affected by the environment. Ultimately healthcare design is directed toward pursing healing environments through by means of Evidence-based Design (EBD). From this BIM is realized to be a link between healthcare design and the healthcare professionals due to the purpose of coordinated data transfer which BIM offers and the necessary reliable data required for EBD.

Investigating the connection between BIM and healthcare took researching the environment of patients and caregivers through established EBD knowledge. The investigation also entailed understanding that through BIM and assembly of organized parts in healthcare are managed as healthcare modules providing accessibility for building design configuration and inquiry in an isolated mode. Additionally, tools/equipment is included in the exploration of BIM and healthcare due to the necessity of the equipment for healthcare services.

Findings reveal that the initial setup for applying Building Information Modeling (BIM) in the healthcare design took a significant amount of time. This involved making decisions about what types of information are foundational and have priority throughout the design process, which front-loads important decisions. The decisions for what types of information and how the information is processed determine the outcome of available data. A large sum of these decisions would be involved in pre-design level of project, even more so pre-project. Healthcare designers and professionals would need to establish the priority of healthcare design issues prior to actual design work. In doing this, the detailed information desired to evaluate for the advancement of healthcare design would also contribute to the growth of EBD.

While BIM is more commonly applied in the design and construction industry, the methods for BIM in healthcare design are different because the information contributes largely to the healthcare design and the healthcare profession. Both building and healthcare professionals are responsible for continuous information exchange in order to utilize the collected data with BIM for applying EBD in the process of healthcare design development. Recognized in this research is that BIM tools are more adequate in managing building industry issues and while they can be useful to healthcare professionals, either one of two things should be considered, 1) the commonly recognized BIM tools can be somewhat shoehorned for the purpose of evaluating information and data according to EBD or 2) it is necessary to identify compatible healthcare data management systems and include them in the collection of BIM tools as contributing means for healthcare design.

The phasing, prototyping, and baseline model of BIM become a solid foundation for updating future redesign projects and as a standalone report of collected data for contributing to EBD. Each of these strategies are founded on the decisions for setting up rules and parameters in order to produce outcomes which reflect detail issues desired to be evaluated in healthcare design. The decisions for specific evaluations are included in the early stages of the design process. The reliability of data outputs is defined by the input setup of rules in BIM tools and how they communicate with one another. This is dominant in phasing and prototyping. The role of phasing is most in sync within the frame of design and construction; outside of that arena its usefulness is yet to be clearly determined. Prototyping includes the availability for being useful in new and ongoing projects by its nature to be used and developed as is, or by healthcare designers/professionals looking to identify environmental issues in a specific setting. The flexibility of prototypes allows for specific scenario testing in details aspects of healthcare design. Next, the strategy for using baseline modeling is dependent on setup but also in communication output. The purpose of baseline modeling defined in this research is for the benefit of making available a sound information basis for future design and including re-design circumstances. Available information is dependent on the agreement between healthcare designers and professionals. After the source of data information is available, any future application of the given information is available for research and can be used for credible case studies contributing to formal investigations. Findings from these strategies reveal that how BIM tools are applied for design investigations affects the data outcomes. The method of processing a design through BIM should reflect specific design details which are desired for exploration. The data results are then clearly supportive of EBD explorations. Referring to Figure 65 shows an overview relationship diagram of the three BIM strategies along a generic timeline of a design project.

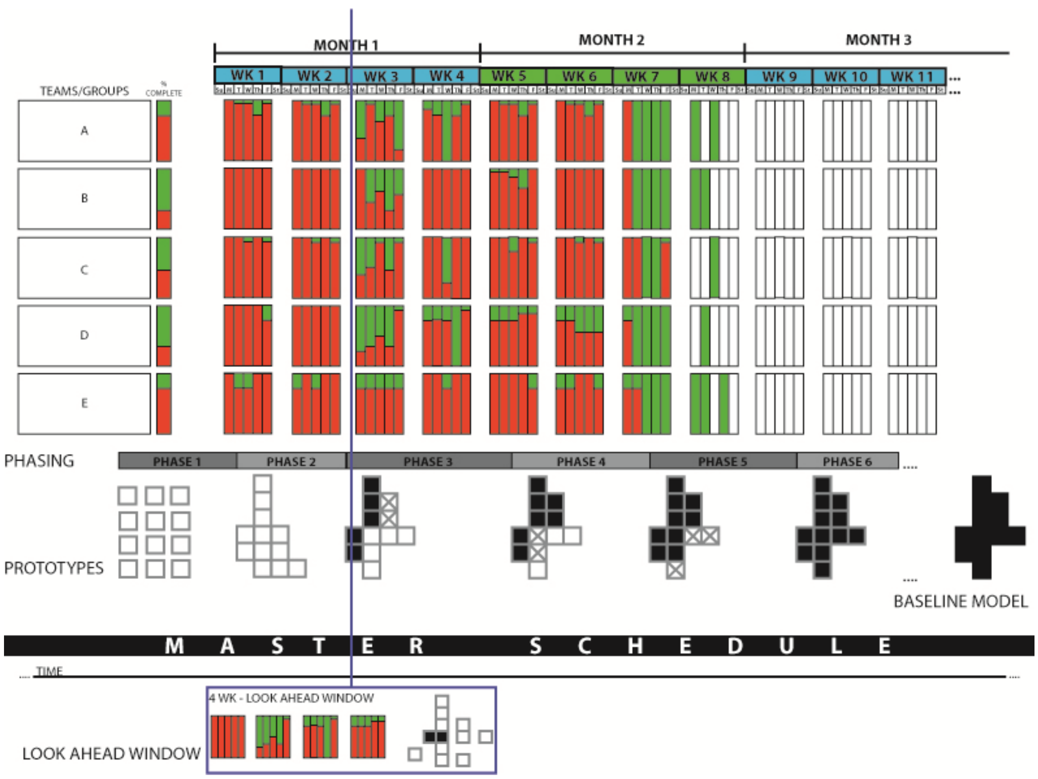


Figure 65 *Diagram of combined BIM strategies.*

In addition to BIM supporting EBD, it is also necessary to contribute formal explorations. While information is made available through BIM, EBD requires setting up goals and objectives founded on current evidences. BIM is used as a place for controlled study, analysis and gathering outcomes; is used for hypotheses and measure. The information gathered using BIM tools would need to shared publically and submitted for publication in order for it to truly be accepted as EBD. So while, informally BIM is a large contributor to concept of EBD another level of evaluation by academic standards is required before it can be officially be identified as credible.[95] During the BIM process it is important to identify key issues of EBD which are desired for investigation.

Fundamentally, the learning curve for using BIM tools and applications in healthcare design is still challenging even though the productivity and quality of this healthcare renovation project increased remarkably with the suggested methods of BIM. Currently BIM tools more adequately supports information transfers among building industry professionals compared to healthcare professionals. Most available BIM tools are originally created based on design industry standards. These being the case, healthcare professionals are likely to be less in tune with the methods for managing information regarding the healthcare environment. Therefore, each profession must be represented by its own BIM manager to facilitate the information and guide the BIM process for healthcare design. Perhaps in this early era of facilitating BIM for healthcare this is a challenge but with the exponential contribution of information resulting from the relationship of BIM and healthcare the optimistic probability of BIM tools, strategies and methods will become more universal between the two industries.

[95] Kirk Hamilton, "The four levels of evidence-based practice," *Healthcare Design*, no. November (2003).

9. GLOSSARY

AIA: American Institute of Architects

Baseline Model: [BIM] a post-construction BIM model that was originally developed during the design of the building as a new construction project or initially integrated into a project of a building as a renovation/redesign project; contains the previous design work and provides accurate information regarding the building's functions and attributes.

Building Information Modeling (BIM): [process-oriented definition] cooperative actions between building industry professionals and client user groups, all using available 3D applications and other digital media for simultaneous and consistent data sharing in an on-going design project.

BIM tools: Information coordinating systems.

CDC: Center for Disease Control

CFD: Computational Fluid Dynamics

Diagnostic: concerned with diagnosis – process of identifying a medical condition or disease by its signs, symptoms, and from the results of various procedures.

Evidence-based Design (EBD): using the collected data from credible research, evaluations and evidence gathered from the operations of the patients, doctors, clients and other partakers of the health facility become critical factors to make design decisions.

Evidence-based Medicine (EBM): [formal] the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients; [practice] integrating individual clinical expertise with the best available external clinical evidence from systematic research.

FGI: Facility Guidelines Institute

Healthcare module: [BIM] an assembly of organized components, based on healthcare department needs, contained together and maintaining an independent nature.

HEPA: high-efficiency particulate air

HIPAA: Health Insurance Portability and Accountability Act

Look-ahead window: allowed preview of the next phase before the phase commences; allowed view of schedule of activities to remain to be ready for execution when scheduled; derived from look-ahead scheduling based on an amount of time in advance that can be accurately forecasted of future events.

MRI: Magnetic Resonance Imaging

NFPA: National Fire Protection Association

Nosocomial: taking place or originating in a hospital

Obstetrics: the branch of medicine that deals with the care of women during pregnancy, childbirth, and the recuperative period following delivery.

Phase: [BIM] process for providing the ability to forecast the development of on-going design project and its schedule.

Pediatrics: the medical specialty concerned with the development, care, and treatment of children from birth through adolescence.

Prototype: [BIM] scaled modeling relationship between category, families and instances.

Treatment: care provided to improve a situation.

Wayfinding: A word that has gained popularity with the adoption of the Americans with Disabilities Act (ADA). In its most literal sense, wayfinding is the ability of a person to find his or her way to a given destination. While the words and graphics on a building's signs are important to the process, wayfinding also depends on the information inherent in a building's design.

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